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The potential for improved transportation of raw and beneficiated coal in Iowa

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CHAPTER I. INTRODUCTION AND OBJECTIVES

Introduction

The Iowa coal industry reached a production peak in 1917 with an annual volume of 9,200,000 tons of coal. A major portion of the early coal production in Iowa was consumed by the railroad industry. Following the Civil War, several Iowa railroads engaged in a rail construction program that extended through southern Iowa. Iowa coal, prior to the discovery and development of the Wyoming coal fields, represented the last coal available to the railroads on the route west.

Many factors have contributed to the decline in Iowa coal production to the estimated 1976 level of 592,000 tons annually. Principal among these are: 1) the discovery of vast deposits of coal in the west; 2) the conversion by the railroad industry to diesel fuel during and after World War II; 3) discriminatory regulations beginning in World War I that favored alternate fuels; 4) superior transportation and handling characteristics of alternate fuels; and more recently 5) federal environmental regulations.

Paradoxically, consumption of coal in Iowa, since 1960, has been increasing. Iowa, which ranks as the twenty-first largest coal user in the United States, expanded its utilization of coal since 1970 by 9.4 percent while U.S. consumption increased by 7.1 percent. The annual difference between Iowa coal consumption and coal production is Iowa's net coal deficit. This net coal deficit, steadily increasing since 1960, represents the amount of coal that must be imported from the nine states that are currently supplying 90.2 percent of Iowa's coal needs (4, p. 1).

Reflected in the burgeoning net coal deficit is the failure of the Iowa coal industry to maintain its position in an expanding market. In a report entitled, "Economics of Mining Coal in Iowa," Dr. Michael Boehlje and James Libbin specify eight factors that should be examined in an analysis of the economic climate in which the Iowa coal industry exists (4, p. 1-22). Several of these factors are paraphrased as follows:

1. The geographic location of Iowa is roughly equidistant from the eastern and western coal-producing areas. This location affords the state two markets for low sulphur coal.

2. A relatively low four-firm concentration ratio, free entry and exit, a low degree of vertical integration, and readily available substitutes given current regulatory practices indicate the existence of substantial competition in the coal industry. The result is an inability to maintain a price that generates excess profits.

3. Larger mining firms, operating over substantially greater and more consistent deposits, and possessing the ability to generate the capital necessary to produce on a larger scale, produce at a significantly lower cost than the mining firm characteristically found in Iowa. Coupled with the competition that exists in the industry, the economics of size argument suggests that the long run price of coal will be close to the cost of production of the lowest producer, a result that is not favorable to the smaller, higher-cost producers.

4. The overburden ratio is the average depth in feet of the overlaying material per foot of coal seam. This ratio has direct affect on the cost of mining. Iowa mining firms, faced with relatively narrow coal seams, spread the cost of overburden removal and reclamation over a smaller coal volume than mining firms in the major producing areas.

5. Large-scale, out-of-state producers utilizing low cost modes of transportation (unit train and barge), currently unavailable to the Iowa coal producers, have a distinct advantage. These out-of-state producers are able to transport coal to Iowa at a delivered price that will afford a substantial margin over production cost and still be price competitive with Iowa-produced coal.

6. Two major dimensions are used in measuring coal quality, Btu and sulphur content. Coal deposits vary in quality across the nation. Iowa coal ranges from 3 to 8 percent sulphur by weight which is approximately 5 to 10 times the allowable amount mandated by the Environmental Protection Agency in the Clean Air Act of 1971 for generating facilities constructed after 1971. The alternatives are: a) blending Iowa coal with imported low sulphur coal; b) beneficiate Iowa coal to reduce its sulphur content. Either alternative further increases the cost of producing Iowa coal.

Table 1.1 illustrates 1975 Iowa coal consumption by source and transportation mode. The major producer of coal used in Iowa in 1975 was Illinois with 44.8 percent followed by Wyoming with 28.5 percent. The primary transportation mode was rail with 77.2 percent of the coal traffic. Iowa coal producers, however, transported 84.2 percent of the domestic production by truck. The ten current Iowa coal producers supplied 320,379 tons of coal in the first half of 1976 and an estimated 592,721 tons for the year. The Iowa coal firms that reported production in 1976 are presented in Table 1.2.

Iowa coal consumption in 1975 as estimated by the United States Department of Interior Bureau of Mines was 6,741,000 tons of coal (4, p. 5). An extensive Iowa State University survey of Iowa coal users consuming 1,000 tons of coal per year or more indicated 1975 consumption in Iowa to be 6,339,264 (3). The principal consumers identified in this survey were the Iowa utility companies totalling 4,997,157 tons of coal or 78.8 percent of the total. Iowa's industrial coal consumption was estimated to be 1,342,107 tons in 1975, 21.2 percent of the Iowa total. Expansion of coal-burning capacity by Iowa utility companies indicates a 175 percent increase in utility coal consumption by 1980 with an additional 15 percent

Table 1.1. 1975 Iowa coal consumption by source and transportation mode[a]

	Tons	Rail	Water	Truck
		(percent)		
Illinois	3,017,000	72.5	26.2	1.4
Wyoming	1,918,000	100.0	0	0
Iowa	644,000	15.8	0	84.2
Montana	372,000	100.0	0	0
Missouri	312,000	92.0	0	8.0
Western Kentucky	248,000	44.0	56.0	0
Colorado	160,000	100.0	0	0
Eastern Kentucky	40,000	100.0	0	0
West Virginia	24,000	100.0	0	0
Utah	6,000	100.0	0	0
Total	6,741,000	77.2	13.8	9.0

[a]Michael Boehlje and James D. Libbin (4, p. 5).

Table 1.2. Estimated 1976 Iowa coal production by active coal mines in tons[a]

Coal firm	
Otley Coal Company	
Jude Coal Company	
ICO Corporation	
Star Coal Company	
Mich Coal Company	
Big Ben Coal Company	
Lovilia #4 Coal Company	
Sutton Coal Company	
Iowa State University Experimental Mine	
Shin Coal Company	
Estimate total production	592,721

[a]Private conversation with an official of Mines and Minerals Division, Iowa Department of Soil Conservation.

increase by 1985. Iowa industry has estimated an increased industrial coal consumption of 40 percent by 1980 and an additional 9 percent by 1985. In 1980 and 1985 utility coal consumption in Iowa is estimated at 85 percent of total coal consumption.

Figure 1.1 illustrates the affect of 1980 and 1985 estimated coal consumption on Iowa's net coal deficit if current trends in domestic coal production continue.

Objectives

Given the large anticipated increase in demand, is it realistic to assume a continuation of the recent production trends of Iowa coal firms? This study formulates an optimal response of a selected Iowa coal-producing area to an anticipated 1980 market situation.

The specific objectives of this study are:

1. Identify potential sources, quality, and available quantity of coal in a selected coal-producing area using data from the Iowa Geological Survey.

2. Establish assembly, in-plant, and delivery costs for a coal beneficiation plant utilizing rail, barge, and truck transportation modes and combinations thereof.

3. Designate optimal coal beneficiation plant locations, assembly areas, and destinations for coal originating in a selected Iowa coal-producing area.

4. Identify optimal origins, destinations, and transportation modes for coal originating outside Iowa.

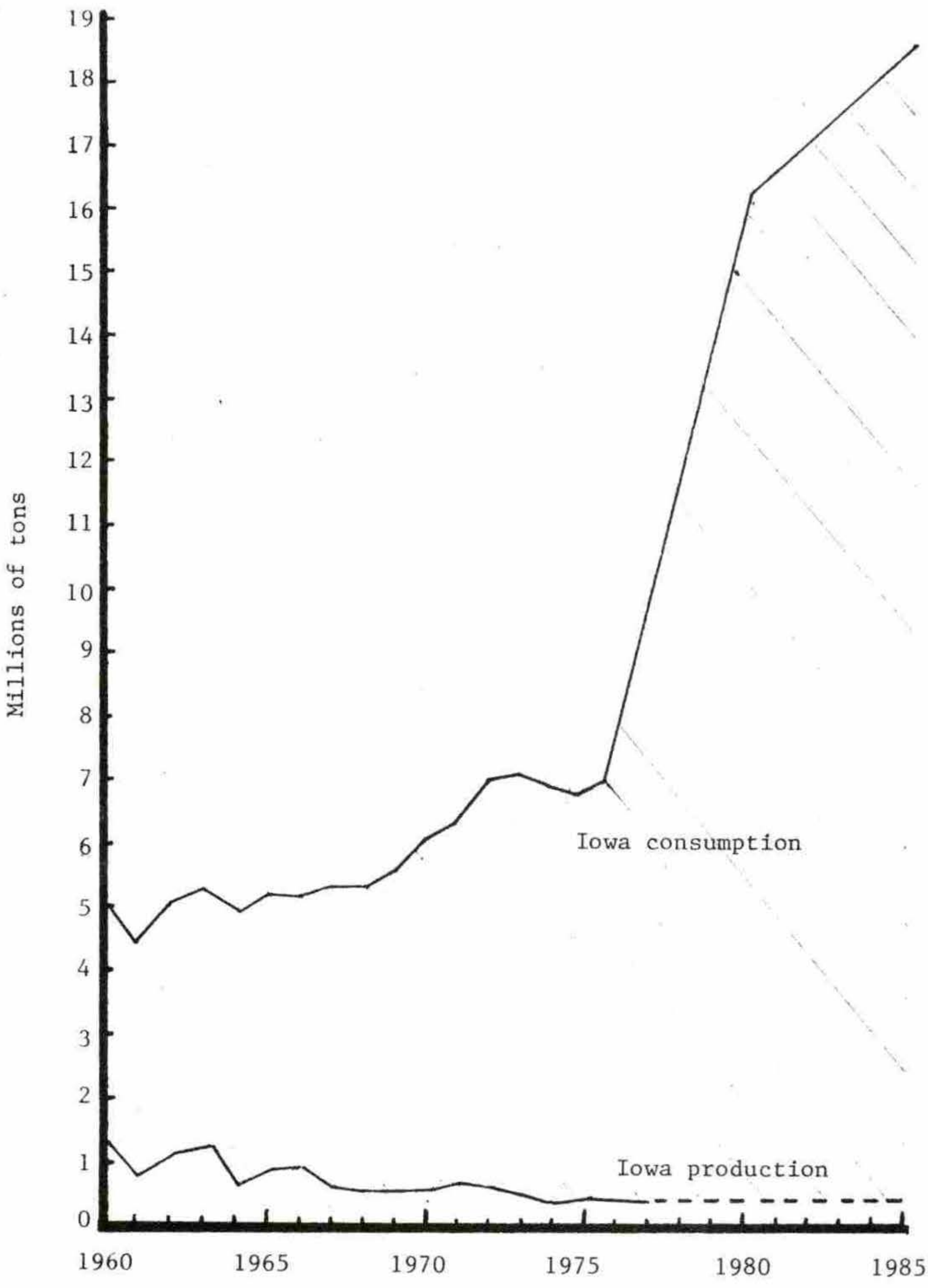

Figure 1.1. Estimated production and consumption of coal in Iowa illustrating Iowa's net coal deficit (shaded area) assuming Iowa coal production is constant after 1976.

CHAPTER II. METHOD OF ANALYSIS

A mathematical programming model was specified to evaluate the feasibility of mining and beneficiating Iowa coal for use by Iowa utility and industrial coal users. The objective of the analysis was to find the least costly method of supplying Iowa's coal needs, subject to constraints on mining capacity, beneficiation plant capacity, sulphur dioxide emission standards and the projected 1980 demand for coal.

The model used both continuous variables, for the mining, transportation and beneficiation activities, and zero-one integer variables, for the construction of beneficiation plants. The model can be summarized as follows:

(1)

$$\text{Minimize } Z = \sum_i P_i M_i + \sum_i \sum_k a_{ik} Uik$$

$$+\psi \sum_i \sum_j b_{ij} \sum_k V_{ijk} + (\psi-1) \sum_j \sum_i c_{ji} \sum_k V_{ijk}$$

$$+ \alpha \sum_i \sum_j \sum_k V_{ijk} + \sum_j \sum_k d_{jk} \sum_i V_{ijk} + \sum_j FC_j Y_j$$

where

Z = total cost.

P_i = price per unit of coal at source i.

M_i = volume of coal supplied by source i.

a_{ik} = minimum transportation plus variable receiving cost per unit of coal shipped from source i to user k.

U_{ik} = volume shipped from source i to user k.

ψ = inverse of the fractional weight recovery at beneficiation plants.

b_{ij} = transportation cost per unit of coal shipped from source i to beneficiation plant site j.

V_{ijk} = volume of clean coal equivalent shipped from source i to beneficiation plant site j to user k.

c_{ij} = transportation cost per unit of refuse and fines shipped from beneficiation plant site j to mine i.

α = variable beneficiation cost per unit of clean coal.

d_{jk} = minimum transportation plus variable receiving cost per unit of clean coal shipped from beneficiation plant site j to user k.

FC_j = annual fixed cost of establishing a beneficiation plant at site j.

Y_j = (0, 1), a binary variable. If site j is used, $Y_j = 1$, otherwise $Y_j = 0$.

The following constraints were imposed on the model:

1. The volume of coal shipped from a source cannot exceed the supply capacity of that source.

   (2) $\sum_k U_{ik} + \psi \sum_j \sum_k V_{ijk} = M_i \leq MC_i$

   where

   MC_i = supply capacity of source i.

2. The volume of coal beneficiated at beneficiation plant site cannot exceed the beneficiation plant capacity.

   (3) $\sum_i \sum_k V_{ijk} \leq BC$ for all j

   where

   BC = beneficiation plant capacity in units of clean coal.

3. The demand for coal at each user must be satisfied. This demand was specified in heating units rather than tons to account for differences in the heating value of coals from different sources.

   (4) $\sum_i \beta_i U_{ik} + \sum_i \sum_j \ell_i V_{ijk} \leq D_k$

   where

   β_i = heating value per unit of raw coal from source i.

ℓ_i = heating value per unit of clean coal from source i.

D_k = exogenously determined demand at user k.

4. Each user was required to meet an aggregate limit on sulphur dioxide emissions. However, each user could blend coal from two or more sources to meet its sulphur dioxide emission standard.

(5) $\sum_i \sigma_i U_{ik} + \sum_i \sum_j \theta_i V_{ijk} \leq S_k = \pi_k D_k$

where

σ_i = units of sulphur dioxide contained in one unit of raw coal from source i.

θ_i = units of sulphur dioxide contained in one unit of clean coal from source i.

S_k = maximum allowable sulphur dioxide emissions at user k.

π_k = maximum allowable emission standard measured as units of sulphur dioxide per unit of heating value.

5. Additional non-negativity restrictions were:

(6) $M_i, U_{ik}, V_{ijk}, Y_j \geq 0.$

CHAPTER III. THE DATA

The data required for the model developed in Chapter II fall into four categories: 1) coal origins including quality, quantity, and price; 2) rates and rate estimates for coal transportation by mode and mode combinations; 3) coal beneficiation costs; and 4) coal users and the projected coal consumption for these users.

Iowa Coal Quantity Analysis

The "Resource Development Map Series 4 for Eleven Counties in South Central Iowa" (hereafter referred to as the Eleven County Report), by the Iowa Geological Survey identifies coal bearing and potential coal bearing strata in an area that includes the bulk of Iowa's past and present coal mining activity. In addition, the Eleven County Report contains a map of the thickness of the unconsolidated material overburden, defined as earth material which has not been consolidated into a rock unit. Unconsolidated material includes sand, gravel, loess, till, and soil. Earth scientists at Iowa State University have superimposed negatives of these maps, producing a composite which can be used to identify areas with potential coal bearing strata accessible to strip mining techniques. Utilizing this composite, an area of approximately three and one-half counties was delineated as the principal future source of Iowa coal. This area is illustrated in Figure 3.1. Preliminary indications from drill sampling conducted by Iowa State University in this area showed the potential for at least one mine producing from fifty to one-hundred thousand tons of coal annually per township. This established the

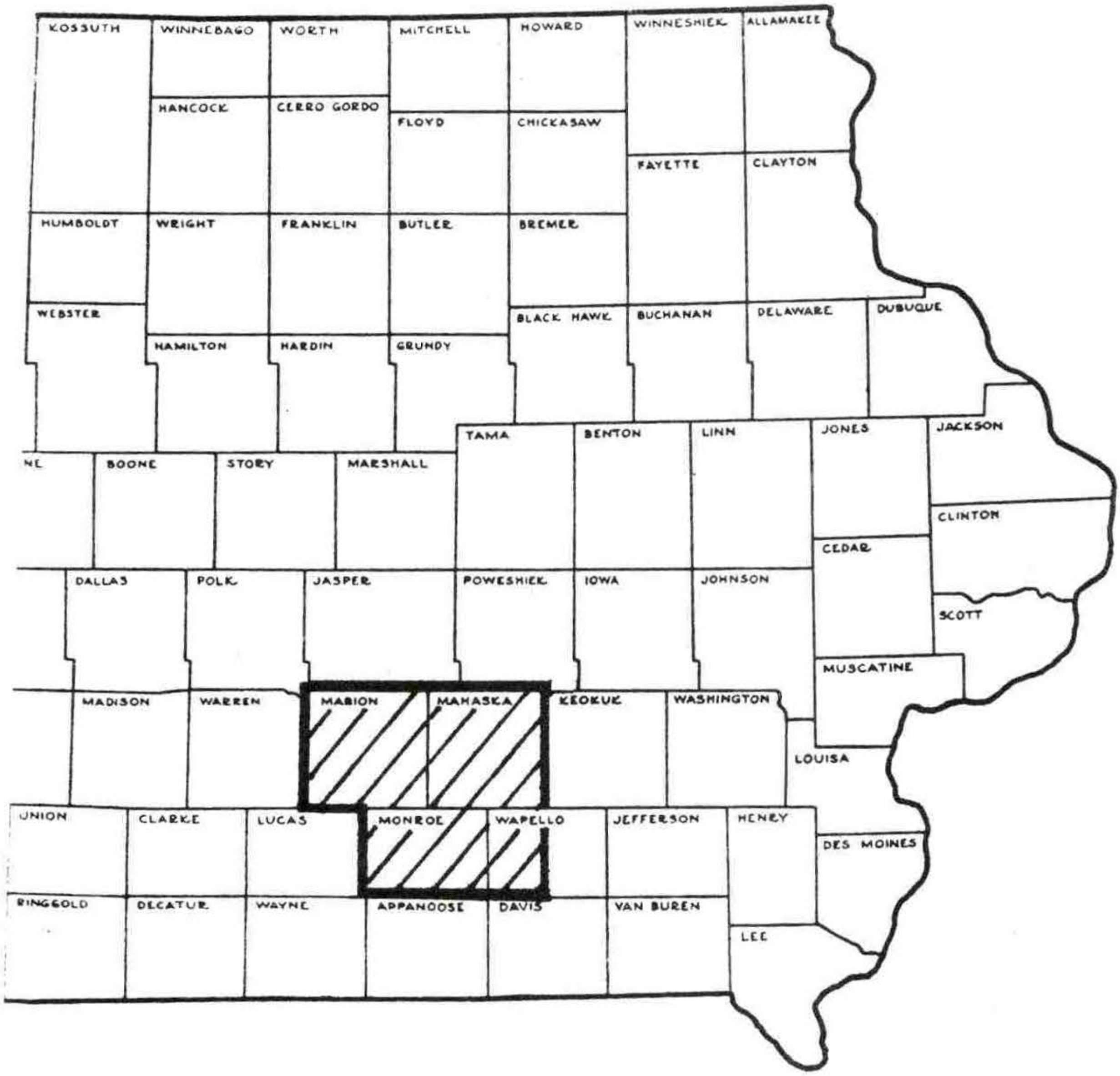

Figure 3.1. The selected Iowa coal producing area.

township, as delineated by township and range coordinates (not to be confused with political townships), as the basic unit for data accumulation in this study. Coal strip mine production in the 50,000 to 100,000 tons per year range is small by industry standards. The constraints on Iowa coal strip mine production are due to the nature and size of the deposits. Iowa coal is deposited in lenticular formations in very thin seams. There is an inconsistency in quality from one deposit to the next that discourages large mining operations due to the risk involved.

The major criteria used in categorizing coal data supplied by the Iowa Geological Survey were quantity, sulphur content, and Btu content. The procedure for estimating obtainable strip mine coal reserves is as follows:

$$(7)\quad Q^{SE}_{S_i} - \{0.25\frac{Q^{SE}_{S_i}}{Q^{SE}_{\Theta_i}} K^{SE}\ RE\} = Q_{N_i} \qquad (i = 1 \ldots\ldots 16)$$

$$(8)\quad Q^{NW}_{S_i} - \{0.33\frac{Q^{NW}_{S_i}}{Q^{NW}_{\Theta_i}} K^{NW}\ RE\} = Q_{N_i} \qquad (i = 1 \ldots\ldots 4)\quad (i = 9 \ldots\ldots 12)$$

$$(9)\quad Q^{NWSW}_{S_i} - \{0.167\frac{Q^{NWSW}_{S_i}}{Q^{NWSW}_{\Theta_i}} K^{NW}\ RE + 0.167\frac{Q^{NWSW}_{S_i}}{Q^{NWSW}_{\Theta_i}} K^{SW}\ RE\} = Q_{N_i} \qquad (i = 5 \ldots\ldots 8)$$

$$(10)\quad 0.9\ Q_{N_i} = Q_{R_i}$$

$$\text{(11)}\quad \frac{\sum_{j=1}^{36} c_{ij}}{36}\, u_i\, Q_{R_i} = Q_{B_i}$$

where

$Q^{SE}_{\Theta_i}$ = original reserves in the i^{th} township (i counting from west to east, north to south for each county) in the southeast quadrant of a county.

$Q^{NW}_{S_i}$ = strip mineable reserves in the i^{th} township in the northwest quadrant of a county assuming no past mining activity.

Q_{N_i} = net strip mineable reserves in the i^{th} township of a county having corrected for past mining activity in the relevant quadrant.

Q_{R_i} = recoverable strip mine reserves having accounted for coal loss due to mining.

R = estimated removal of coal from a county due to past mining activity.

K^{SE} = the percentage of past mining activity attributed to the southeast quadrant of a county.

E = inverse of assumed shaft mining efficiency.

u_i = the percentage of land area in township i with coal bearing strata and 50 feet of unconsolidated material overburden or less.

c_{ij} = the percentage of land area with coal bearing strata and 50 feet of unconsolidated material overburden or less in township i and section j that has been excluded from consideration because it is prime agricultural land or lies beneath cities, rivers, reservoirs, roads or highways.

Q_{B_i} = obtainable strip mine reserves.

Equation 1 obtains a Q_{N_i} for counties containing sixteen townships. Equation 2 obtains a Q_{N_i} for twelve township counties excluding the horizontal center tier of townships. Equation 3 obtains a Q_{N_i} for the horizontal center tier of townships in a twelve-township county.

Only coal seams 28 inches or thicker enter into the calculations. Any coal categorized as being strip mineable is less than 150 feet below the surface.

Equations 1-3 correct raw data on strip mineable reserves obtained from the Iowa Geological Survey for past mining activity. Though shaft mining was the principal method of coal extraction in Iowa's history, much of the past mining activity recovered coal now considered strip mineable. Data on past mining activity was provided by the Iowa Geological Survey by county quadrant. The underlying assumption in Equations 1-3 is that past mining activity was uniformly distributed throughout the quadrant. The 0.25 coefficient in Equation 1 is a result of the assumption that 25 percent of the past mining activity in a four-township quadrant can be associated with any single township in that quadrant. Similar reasoning is associated with Equation 2 for counties with quadrants containing fractional townships totalling three townships in area. Figure 3.2 illustrates the technique used in Equation 3. Townships are labeled 1 through 12 and correspond to the i subscripts in Equations 2 and 3. The dotted lines represent county quadrants labeled I through IV. Quadrant lines in a twelve-township county bisect the center tier of townships resulting in four 18-section areas labeled a through d. The assumption of a uniform distribution of past mining activity within a county quadrant indicates that one-sixth, or 16.7 percent of past coal production can be associated with any 18-section area in that quadrant. The average of past coal production data for areas a and c (or b and d) will estimate the past coal mining activity in townships five and six.

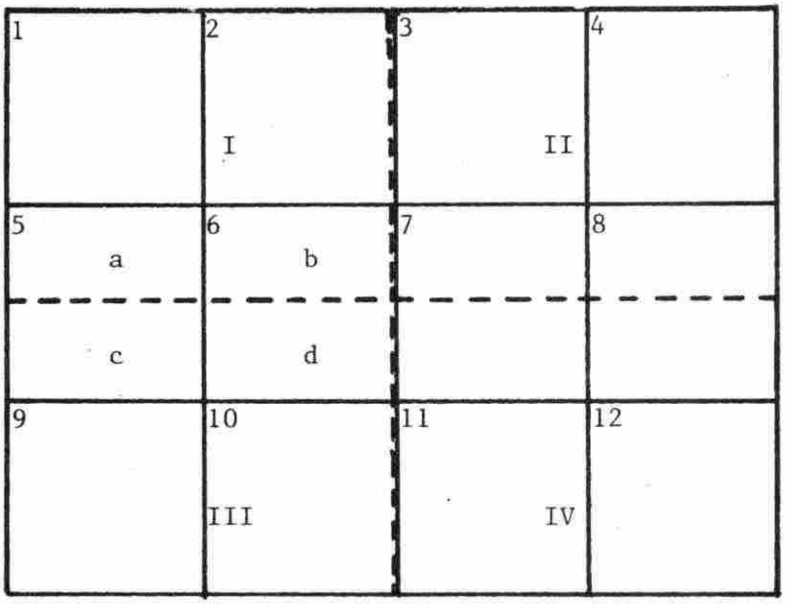

Figure 3.2. Illustration of the technique used for the calculation of Q_{N_i} for the horizontal tier of townships in a twelve-township county.

The expression (E) represents the inverse of the assumed shaft mining efficiency. In this study, shaft mining efficiency is assumed to be 50 percent, indicating that half of the coal present is lost to future recovery as a result of shaft mining. Estimates of actual coal extraction (R) are, therefore, doubled to indicate actual depletion of reserves.

Equations 1-3 estimate net coal reserves (Q_{N_i}) having corrected for past mining activity. Equation 4 further adjusts the reserve estimate by the assumed 90 percent efficiency of a strip mine, i.e., 10 percent of the coal present is lost as a result of strip mining.

The recoverable strip mine reserve figure (Q_{R_i}) is a valid estimate of future production only if 100 percent of the township containing coal bearing strata were to be strip mined. The problem of further data correction becomes one of excluding potential Iowa coal producing land from consideration in this analysis in a manner consistent with the actual economic constraints facing the Iowa coal producer attempting to purchase or lease land for mining.

The Eleven County Report identifies coal bearing strata and unconsolidated material overburden in the selected region. Limiting the comparatively small projected Iowa mine to coal bearing strata with 50 feet or less of unconsolidated overburden, affords a percentage reduction (u_i) of coal reserve data commensurate with the estimated maximum overburden removal capacities of the smaller coal producer. This analysis was accomplished using the Eleven County Report composite map and a grid overlay on a township basis. The United States Department of the Interior Geological Survey topographical maps were studied on a section basis with a grid overlay to determine percentage land area reductions for such obvious mineable land exclusions as cities, reservoirs, rivers, flood plains, highways, and county roads. In addition, prime agricultural land was identified by using topographical map contour lines to indicate flat areas. The exclusion of prime agricultural land not only reflects the economic difficulties in obtaining such highly productive cropland for conversion to coal mining, it also corrects data to reflect the economic desirability of mining the more rugged terrain where coal strata intersect or more nearly intersect the surface.

Small coal strip mines, in the production range projected for Iowa, are limited to a maximum highwall of seventy feet. The highwall height refers to the number of feet of earth material that must be removed to uncover the coal seam. The data received from the Iowa Geological Survey include coal seams 150 feet deep or less. By correcting the quantity data for prime agricultural land, where the bulk of the deeper coal is deposited, no further corrections are necessary to reduce estimated strip mineable reserves. The results of the coal quantity analysis appear in Table 3.1.

Table 3.1. Estimated coal supply by township in a selected Iowa coal producing area

Township North	Range West	Percent of township with coal bearing strata with less than 50 feet of unconsolidated material overburden (u_i)	Percent of area with coal bearing strata with less than 50 feet of unconsolidated material overburden that is not under flat land, towns, reservoirs, etc. ($\overline{c_i \cdot}$)
73	17	34.3	50.7
73	16	36.4	27.5
73	18	94.4	40.7
72	16	20.2	64.0
72	17	16.0	76.8
75	20	97.2	59.7
75	21	79.9	60.7
76	19	44.4	43.0
77	21	56.9	26.4
77	20	41.7	36.2
76	18	27.7	57.5
76	21	42.4	71.0
77	19	22.9	60.8
76	20	37.5	53.4
74	18	91.7	27.6
75	19	63.2	52.5
75	18	39.5	36.8
72	15	41.0	52.8
73	15	13.2	52.5
75	15	20.8	52.1
74	17	81.3	38.5
75	17	18.1	28.9
74	16	27.6	18.0
75	16	41.0	35.2

Scalar transformation (u_i) ($\overline{c_i}$.) as a percent	Recoverable strip mine reserves (Q_{R_i}) in millions of tons	Obtainable strip mine reserves (Q_{B_i}) in millions of tons	Average percent sulphur found in coal samples in the relevant county quadrant
17.4	24.3	4.2	3.11
10.0	17.1	1.7	3.11
38.5	24.5	9.4	3.24
12.9	10.1	1.3	4.27
12.3	8.7	1.1	4.27
58.0	22.6	13.1	5.25
48.5	25.0	12.1	5.25
19.1	20.0	3.8	5.25
15.0	23.9	3.6	5.25
15.1	21.6	3.3	5.25
15.9	17.6	2.8	5.25
30.1	6.1	1.8	5.25
13.9	11.2	1.6	5.25
20.1	7.4	1.5	5.25
25.3	76.8	19.4	5.33
33.2	47.1	15.6	5.33
14.6	21.4	3.1	5.33
21.6	20.7	4.5	5.49
6.9	15.6	1.1	5.49
10.8	46.1	5.0	5.60
31.3	24.5	7.7	5.83
5.2	77.1	4.0	5.83
5.0	49.5	2.5	5.83
14.4	16.4	2.4	5.83

Iowa Coal Quality Analysis

The Iowa Geological Survey furnished the coal quality data used in this study. Core and channel face sample results were obtained on a county quadrant basis. The samples were analyzed for Btu content and percentage of sulphur, ash, and moisture. The results appear in Figure 3.3. as percent sulphur, Btu content per pound, and obtainable reserves (Q_{B_i}) in millions of tons by selected Iowa township within the study area. Diagonally marked townships were excluded from consideration in this study for the following reasons: 1) a high percentage of exposed Mississippian (non-coal bearing) strata; 2) obtainable strip mine reserves (Q_{B_i}) of less than one million tons; or 3) topographical survey maps do not exist.

Origins of Coal Consumed in Iowa

Potential mine sites used in this analysis were obtained from the Eleven County Report composite map of coal bearing strata and unconsolidated material overburden. The north-south, east-west center of the irregularly-shaped eligible area was pinpointed using a grid overlay. The center was then shifted to incorporate the existence of cities, reservoirs, and rivers. All coal origins thus located for Iowa were given location coordinates utilizing the southwest corner of Monroe County as (0, 0). Figure 3.4 illustrates the projected coal origins in the townships considered in this analysis.

	R21W	R20W	R19W	R18W	R17W	R16W	R15W	R14W
T77N	5.25 9794 3.59	5.25 9794 3.26	5.25 9794 1.55					
T76N	5.25 9794 1.83	5.25 9794 1.48	5.25 9794 3.82	5.25 9794 2.81		Mahaska	County	
T75N	5.25 9865 12.11	5.25 9865 13.12	5.33 9851 15.62	5.33 9851 3.11	5.83 10348 4.03	5.83 10348 2.37	5.60 10900 5.00	
T74N		Marion	County	5.33 9851 19.43	5.83 10348 7.68	5.83 10348 2.48		
T73N				3.24 10181 9.41	3.11 10798 4.23	3.11 10798 6.72	5.49 10294 1.08	
T72N					4.27 11549 1.11	4.27 11549 1.31	5.49 10294 4.47	
T71N			Monroe	County			Wapello	County

S(%)
Btu per pound
Q_{B_i} in millions of tons

Figure 3.3. Estimated percent sulphur, Btu per pound, and obtainable reserves (Q_{B_i}) of coal located in selected townships within the Iowa study area.

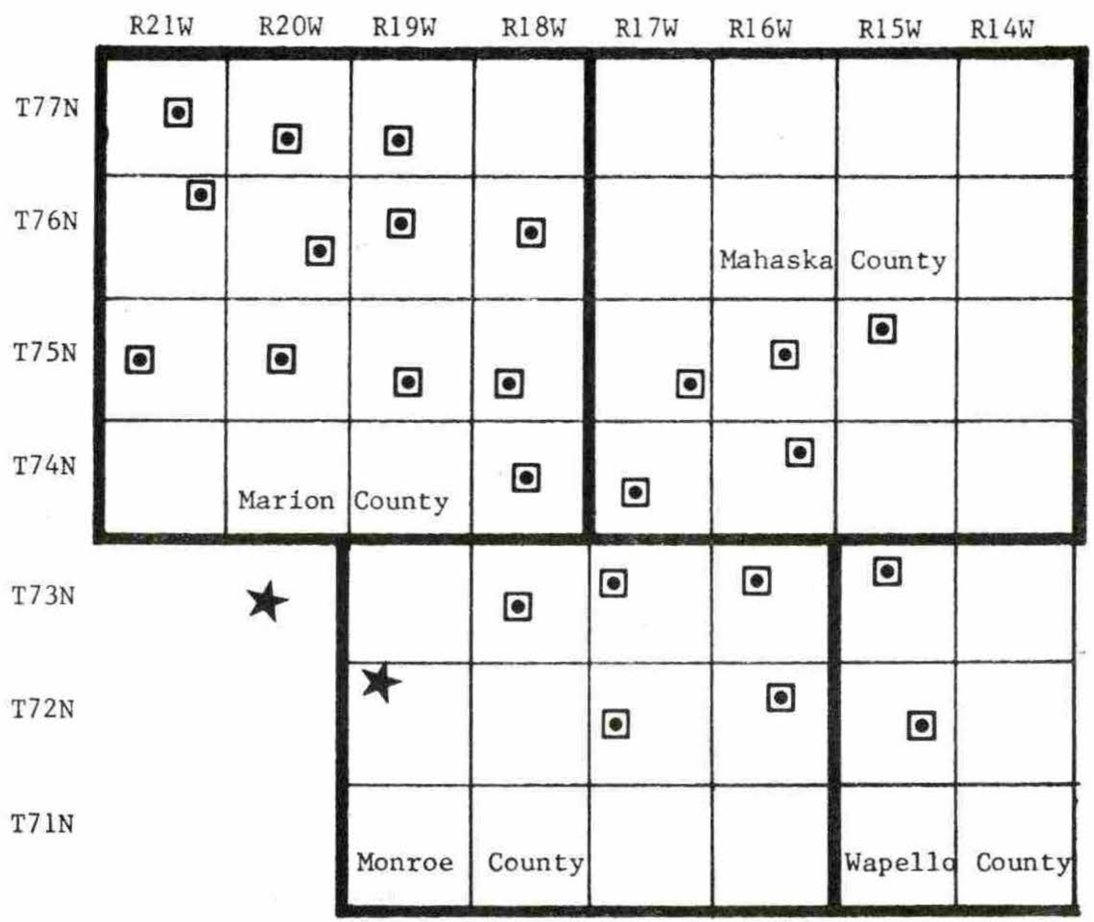

Figure 3.4. Potential and existing Iowa coal mine origins assumed in this study. Potential mine origins are indicated by a square, existing origins by a star.

All major 1977 out-of-state suppliers of coal consumed in Iowa are considered in this analysis. Table 3.2 presents origin and coal quality data for these suppliers.

Coal Prices and Iowa Coal Price Function

Table 3.3 presents 1977 f.o.b. bid coal prices that have been adjusted for increases due to the Surface Mining Control and Reclamation Act of 1977. Iowa bid prices for surface mined and shaft mined coal were used to establish a functional relationship between sulphur content and price for potential mine sites in Iowa. The relationship is estimated as follows:

$$(12) \quad P_i = \$1.93 + \$21.12\ (S_i)^{-0.29}$$

where

P_i = f.o.b. price of coal of quality type i including the increase due to the Surface Mining Control and Reclamation Act of 1977.

S_i = the percentage sulphur content by weight of coal quality type i.

Truck Cost Functions

Equipment

The role of trucks in coal mining is varied. In this study, a number of assumptions have been made, based on actual coal mining and coal hauling operations, regarding the type of equipment used in coal transportation by truck. Coal will be transported from mine to cleaning plant or stockpile by a tandem-axle dump truck. This type of vehicle is especially suited for tight maneuvering at the mine site and special

Table 3.2. Out-of-state supply origins for coal consumed in Iowa featuring Btu and sulphur content analysis[a]

Origins	Btu per pound	Percent sulphur
Gillette, WY	8,100	0.48
Sheridan, WY	9,300	0.50
Sparta, IL	11,400	2.90
Canton, IL	11,000	3.25
West Harrisburg, IL	11,400	1.97
Nortonville, KY	10,500	2.50
Unionville, MO	12,455	2.62

[a] C. Phillip Baumel, John Miller, and Thomas Drinka (3).

Table 3.3. Estimated 1977 coal prices based on 1977 f.o.b. bid prices and coal qualities. The effects of the 1977 Surface Mining Control Act are incorporated.

Origins	Btu per pound	Percent sulphur	Dollars per ton
Gillette, WY	8,100	0.48	8.15
Sheridan, WY	9,300	0.50	12.65
Sparta, IL	11,400	2.90	22.20
Canton, IL	11,000	3.25	24.70
West Harrisburg, IL	12,455	1.97	23.35
Nortonville, KY	11,400	2.50	22.33
Unionville, MO	10,500	2.62	20.61
Iowa Mines			
Lovilia #4	9,772	3.04	15.01
Big Ben	10,225	4.60	13.53
Mich	9,387	5.81	12.15
ICO	9,676	3.82	15.65
Star	10,338	7.65	11.08
Otley	8,929	6.26	13.33
Sutton	9,360	4.00	12.67

dumping situations. In addition, the tandem-axle dump truck is best suited for backhauling sludge (rejected material from the coal cleaning process) to the mine site.

Coal distribution by truck from a cleaning plant or stockpile will be accomplished with a tandem-axle dump truck pulling a pup trailer or a tractor-twin-belly dump trailer combination.

Methodology

The basic model for estimating operating costs of trucks was obtained from a recent rail branch line study done at Iowa State University (2, p. 368). In this model, trucking costs are divided into three components: 1) variable costs which are associated with trip distance; 2) fixed costs; 3) transfer costs which are a function of the cost of loading and unloading. Total cost can be represented by the following equation:

$$(13) \quad TC_v = FC_v + VC_v M_v + TR_v$$

where for vehicle-type v

TC_v = total cost per year.

FC_v = fixed cost per year.

VC_v = variable cost per mile.

M_v = total miles per year.

TR_v = transfer cost per year.

Variable costs include fuel, oil and oil filters, tires, and drivers' wages. These were converted to a cost per mile as follows:

$$\text{Fuel cost per mile} = \frac{\text{fuel cost per gallon}}{\text{miles per gallon}}$$

$$\text{Oil and oil filter cost per mile} = \frac{\text{oil and oil filter cost per change}}{\text{miles per oil change}}$$

$$\text{Tire cost per mile} = \frac{\text{(tire cost per tire) x (tires per vehicle)}}{\text{miles per tire}}$$

$$\text{Driver wage per mile} = \frac{\text{wage per hour}}{\text{miles per hour}}$$

Fixed costs include interest and depreciation, license fees, insurance, highway use taxes, overhead expense, and maintenance and repairs.

Once purchase price, salvage value, interest rate, and life expectancy are obtained for the equipment, annual equivalent cost calculations can be computed using the following formula:

$$(14) \quad AEC - B(\tfrac{a}{p})^{i}_{n} - V(\tfrac{a}{f})^{i}_{n}$$

where

AEC = annual equivalent cost.

B = initial cost of the equipment.

V = salvage value.

i = interest rate (or rate of return).

$$(\tfrac{a}{p})^{i}_{n} = \frac{i(1 + i)^{n}}{(1 + i)^{n} - 1} = \text{annual equivalent of a present sum}$$

$$(\tfrac{a}{f})^{i}_{n} = \frac{i}{(1 + i)^{n} - 1} = \text{annual equivalent of a future sum}$$

This analysis assumes a before-tax rate of return on investment of ten percent. No provision was made in the analysis for the effect of income or corporate taxes. Purchase price in the case of a truck tractor is assumed to be net of tires. Salvage value is assumed to be net of 50 percent of tires.

Maintenance and repair costs are assumed to be a proportion of the purchase price of the vehicle and are estimated as follows:

(15) $MRC_v = \alpha_v P_v$

where

MRC_v = maintenance and repair cost per year.

α_v = annual maintenance and repair percentage of purchase price.

P_v = purchase price less tires.

Transfer costs are the costs of the driver waiting time to load and unload and are estimated as follows:

(16) $TR_v = N_v TW$

where

TR_v = transfer cost per year of vehicle-type v.

N_v = number of trips per year of vehicle-type v.

T = transfer time (including waiting time, loading time, and unloading time) expressed as hours per trip.

W = driver wage per hour.

The number of trips per year for coal movement is based on trip distance, speed, transfer time, and the number of working days per year and is estimated as follows:

(17) $$N_v = \frac{H_v}{\frac{D}{S} + T}$$

where

N_v = number of trips per year of vehicle-type v.

H_v = total working hours per year of vehicle-type v.

D = round-trip distance expressed as miles per trip.

S = speed expressed as miles per hour.

T = transfer time expressed as hours per trip.

The average cost per mile is computed as follows:

$$(18) \quad CM_v = \frac{TC_v}{M_v}$$

where

CM_v = average cost per mile of vehicle-type v.

The average cost per ton-mile is estimated by the following equation:

$$(19) \quad CTM_v = \frac{TC_v}{M_v PL_v}$$

where for vehicle-type v

CTM_v = average cost per ton-mile.

PL_v = payload in tons.

Assumptions

The basic assumptions in this analysis are:

1. There are 275 working days, or 2200 working hours per year.

2. Diesel fuel price is assumed to be $.50 per gallon.

3. Driver wages are assumed to be $6.25 per hour for non-union drivers and $8.40 per hour for union drivers. These wages include fringe benefits.

4. Truck transportation cost alternatives are considered depending upon the fleet size of the firm. The large trucking firm, with a fleet size sufficient to achieve economies of scale, realizes advantages in the following areas:

   a. Equipment purchasing. Volume transactions and commensurate discounts are available to the large firm. Savings are not only realized on large items like semi-tractors, but volume purchases of parts; and even parts repair programs become practical in large-scale operations.

b. Fuel economy. Superior maintenance, monitoring, and incorporation of new technology result in higher average mileage for the large firm.

c. Transfer time. Reported and observed transfer times are noticeably lower for the large truck firm. This is a result of generally superior equipment technology featuring rapid unloading and a superior monitoring of driver efficiency.

Partially offsetting these advantages of large size, the large firm characteristically pays union-scale wages. Costs associated with the large trucking firm are referred to as Alternative I Costs.

Alternative II Costs reflect those facing the smaller trucking firms typical of those currently transporting Iowa coal. Characteristically, the smaller firm is unable to make volume transactions and is unable or slow to incorporate new technology. Partially offsetting the disadvantages inherent in a smaller fleet size, the small trucking company typically pays non-union scale wages.

5. The speed-distance matrix applies to all vehicles in this study. The matrix is applicable in "gate-to-gate" transport. Movement within the mine pit or dumping area is assumed to be a part of transfer time. The speed-distance matrix is presented in Table 3.4.

6. The truck cost analysis is based on actual May, 1977, price levels in Iowa.

Alternative I estimated coal hauling costs

Equipment Tractor-twin-belly dump trailer.

Fixed costs The fixed costs considered for this vehicle are:

1. Interest and depreciation costs. Interest and depreciation costs are based on an annual equivalent cost using 10 percent interest rate and a life expectancy of 4 years for the tractor and 15 years for the trailer. Purchase price less tires is \$33,483 for a tractor with the following options:

   a. Engine--270hp diesel.
   b. Transmission--7 speed.
   c. Tires--1100/22.5D rear and 1100/22.5S front
   d. Power steering.

Table 3.4. Speed-distance matrix for coal transportation by truck

Round Trip Distance (miles)	Speed (mph)
0.50	14
1.00	18
1.50	21
2.00	25
3.00	32
4.00	34
10.00	40
15.00	42
20.00	45
30.00	46
50.00	47
100.00	48
150.00	49
200.00	51
250.00	52
300.00	53
350.00 and above	55

e. Radio.
f. "Fuel squeezer" equipment.

The purchase price less tires for the twin-belly dump trailer is $22,025. Salvage value less tires is estimated to be $8,706 for the tractor and $7,575 for the trailer.

2. License fee. The license fee for the combination is $1,300 per year. The road use tax is $220 per year.

3. Insurance cost. Insurance costs vary greatly with the level of coverage. In this analysis, the tractor-trailer liability and collision coverage was assumed to be $2,410 per year.

4. Maintenance and repair costs. Annual maintenance and repair costs are assumed to be 6.7 percent of the purchase price of the vehicles.

5. Management and overhead costs. Management and overhead costs are assumed to be $3,636 per year for the tractor-trailer combination.

Variable costs The variable costs considered in this analysis are:

1. Fuel consumption. Fuel consumption for the tractor-trailer combination is based on the new "fuel squeezer" options. Fuel consumption is estimated at 6.55 miles per gallon when traveling empty and 5.75 miles per gallon when loaded.

2. Oil and oil filter cost. Oil and oil filter cost per change is estimated to be $33.90. The oil and filter are changed every 22,000 miles.

3. Tire costs. Tire costs are based on a Bandag re-capping program with up to four re-caps per tire. Tire costs in this program are $0.019 to $0.021 per mile depending on conditions for the tractor-trailer combination. Dealer price estimates (including tax) of the tires used are:

Size	Ply	Price	No. used	Life
1100/22.5S	16	$271.19	2	4 re-caps
1100/22.5D	16	$246.83	16	4 re-caps

4. Driver wages. Driver wages for the tractor-trailer combination are union scale or $8.40 per hour with fringe benefits included.

Transfer time   Transfer time changes with the nature of the operation, weather conditions, and the proficiency of the driver, front-end loader or conveyor operator. In this analysis, coal loading time at a coal beneficiation plant is estimated at five minutes. Unloading at a drive-over stockpile is assumed to require 1.5 minutes. No backhaul, i.e., a return payload to the point of origin, is anticipated with this type of equipment.

Average cost per mile and per ton-mile   The estimated cost per mile and per ton-mile are presented in Table 3.5.

Equipment   Tandem-axle dump truck.

Fixed costs   The fixed costs considered for the tandem-axle dump truck are:

1. Interest and depreciation costs. Interest and depreciation costs are based on annual equivalent cost for the tractor with aluminum dump box. The annual equivalent cost calculation assumes a 10 percent interest rate, a four-year life expectancy of the tractor, and an eight-year life expectancy for the aluminum dump box. Purchase price less tires for the tractor is $33,483 with the following options:

    a. Engine--270hp diesel.
    b. Transmission--7 speed.
    c. Tires--1100/22.5D rear and 1100/22.5S front.
    d. Power steering.
    e. Radio.
    f. "Fuel squeezer" equipment.

    Purchase price for the aluminum dump box is estimated to be $6,950. Salvage estimates for the tractor and dump box are $8,706 and $500 respectively.

2. License fee. The license fee, based on a 24.6-ton gross weight, is $735 per year. Federal use tax is $160 per year.

3. Insurance costs. Annual insurance costs are estimated to be $1,200.

Table 3.5. Estimated Alternative I costs of hauling coal in a tractor-twin-belly dump trailer in mid-1977 prices with a 0 percent backhaul

Round trip distance	Speed in miles per hour	Number of trips per year	Total annual mileage	Fixed cost per year
		Tractor-twin-belly dump trailer[a]		
10.00	40	6,111	61,110	$22,796.39
15.00	42	4,709	70,635	22,796.39
20.00	45	3,967	79,340	22,796.39
30.00	46	2,886	86,580	22,796.39
39.98	47	2,290	91,554	22,796.39
		Tractor-twin-belly dump trailer[b]		
40.00	47	2,289	91,560	22,796.39
50.00	47	1,874	93,700	22,796.39
100.00	48	1,003	100,300	22,796.39
149.98	49	693	103,936	22,796.39
		Tractor-twin-belly dump trailer[c]		
150.00	49	693	103,950	22,796.39
200.00	51	554	109,000	22,796.39
250.00	52	447	111,750	22,796.39
300.00	53	381	114,300	22,796.39
350.00	55	339	118,650	22,796.39
400.00	55	297	118,800	22,796.39

[a]Trucking cost function for one-way trip distances from 5 to 19.99 miles; α = \$0.13271616, β = \$0.04202126.

[b]Trucking cost function for one-way trip distances from 20 to 74.99 miles; α = \$0.13681258, β = \$0.04204056.

[c]Trucking cost function for one-way trip distances from 75 to 200 miles; α = 0.5678894, β = \$0.03634562.

Variable cost per mile	Transfer cost per year	Total cost per year	Average cost per mile	Average cost per ton-mile
		Tractor-twin-belly dump trailer[a]		
\$0.31403	\$5,646.56	\$47,633.33	\$0.779469	\$0.000684
0.30403	4,351.11	48,622.66	0.688365	0.000604
0.29070	3,665.51	49,525.77	0.624222	0.000548
0.28664	2,666.66	50,280.23	0.580737	0.000509
0.28275	2,115.96	50,799.61	0.554858	0.000487
		Tractor-twin-belly dump trailer[b]		
0.28072	2,115.04	50,614.46	0.552801	0.000485
0.28072	1,731.58	50,831.75	0.542495	0.000476
0.27700	926.77	51,506.26	0.513522	0.000450
0.27343	640.33	51,855.82	0.498920	0.000438
		Tractor-twin-belly dump trailer[c]		
0.27150	640.33	51,659.00	0.496960	0.000436
0.26478	503.58	52,160.54	0.478537	0.000420
0.26161	413.03	52,444.16	0.469299	0.000412
0.25856	352.04	52,701.91	0.461084	0.000404
0.25280	313.24	53,104.02	0.447569	0.000393
0.25280	274.43	53,103.13	0.446996	0.000392

4. Maintenance and repair costs. Annual maintenance and repair costs are estimated to be 6.7 percent of purchase price of the vehicle.

5. Management and overhead costs. Management and overhead costs are estimated to be $3,636 per year for the tandem-axle dump truck.

Variable costs The variable costs for the tandem-axle dump truck are as follows:

1. Fuel consumption. Fuel consumption for the tandem-axle dump truck is estimated to be 5.04 miles per gallon loaded and 6.04 miles per gallon when empty.

2. Oil and oil filter cost. Oil and oil filter cost per change is estimated to be $33.90. Oil and filter are changed every 20,000 miles.

3. Tire costs. Tire costs are based on a Bandag re-capping program with approximately four re-caps per tire. Tire costs in this program are $0.11 per mile for the tandem-axle dump truck. A ten percent cost increase is included to account for the off-road conditions under which this vehicle will operate. Dealer price estimates (including tax) of the tires used are:

Size	Ply	Price	No. used	Life
1100/22.5D	16	$271.19	2	4 re-caps
1100/22.5D	16	$246.83	8	4 re-caps

4. Driver wages. Driver wages for the tandem-axle dump truck are union scale or $8.40 per hour with fringe benefits included.

Transfer time The average loading time from gate entrance to gate exit for the tandem-axle dump truck is estimated to 5.0 minutes. Loading is by front-end loader. The average unloading time for this vehicle is estimated to be 3.5 minutes.

Average cost per mile and per ton-mile The estimated costs per mile and per ton-mile are given in Table 3.6.

Table 3.6. Alternative I estimated costs of hauling coal in a tandem-axle dump truck in mid-1977 prices with 0 percent backhaul

Round trip distance	Speed in miles per hour	Number of trips per year	Total annual mileage	Fixed cost per year
		Tandem-axle dump truck[a]		
0.50	14	12,520	6,260	$18,696.01
1.00	18	11,250	11,250	18,696.01
1.50	21	10,405	15,608	18,696.01
2.00	25	10,000	20,000	18,696.01
3.00	32	9,411	28,233	18,696.01
4.00	34	8,538	34,152	18,696.01
10.00	40	5,641	56,410	18,696.01
15.00	42	4,425	66,375	18,696.01
20.00	45	3,764	76,280	18,696.01
30.00	46	2,777	83,310	18,696.01
40.00	47	2,219	88,760	18,696.01

[a]Trucking cost function for one-way trip distances from 0.25 to 20 miles; α = \$0.13680876, β = \$0.04195294.

Variable cost per mile	Transfer cost per year	Total cost per year	Average cost per mile	Average cost per ton-mile
		Tandem-axle dump truck[a]		
$0.71195	$14,723.51	$37,875.32	$6.050529	$0.008067
0.57862	13,229.99	38,435.43	3.416482	0.004555
0.51195	12,236.27	38,922.54	2.493834	0.003325
0.44795	11,759.99	39,414.99	1.970749	0.002628
0.37445	11,067.33	40,335.18	1.428653	0.001905
0.35901	10,040.68	40,997.56	0.200443	0.001601
0.32195	6,633.81	43,491.02	0.770981	0.001028
0.31195	5,203.80	44,605.48	0.672022	0.000896
0.29862	4,426.46	45,602.32	0.605769	0.000808
0.29456	3,265.75	46,501.44	0.558174	0.000744
0.29067	2,609.54	48,105.72	0.530709	0.000708

Alternative II estimated coal hauling costs

Equipment Tandem-axle dump truck with pup trailer.

Fixed costs The fixed costs considered for this vehicle are:

1. Interest and depreciation costs. Interest and depreciation costs are based on an annual equivalent cost using a 10 percent interest rate, a four-year life expectancy for the tractor, an eight-year life expectancy for the aluminum dump box, and a ten-year life expectancy for the pup trailer. Purchase price less tires for the tractor is $34,640 with the following options:

   a. Engine--270hp diesel.
   b. Transmission--7 speed.
   c. Tires--1200/20 front, 1100/20 rear.
   d. Radio.
   e. Power steering.

   Purchase price less tires for the pup trailer is estimated at $11,251. Purchase price for the aluminum dump box is estimated at $6,950. Salvage values for the tractor, pup trailer, and aluminum dump box are $9,006, $3,870, and $500, respectively.

2. License fee. The license fee for the tandem-axle dump truck with pup trailer is $1,300 per year based on a 35.8-ton gross weight loaded. Highway use taxes are $220 per year.

3. Insurance costs. Insurance costs for the combination are estimated at $2,620 per year.

4. Maintenance and repair costs. Maintenance and repair costs per year are assumed to be 6.7 percent of the purchase price of the truck-trailer combination.

5. Management and overhead costs. Management and overhead costs are assumed to be $3,636 per year for the tandem-axle dump with pup combination.

Variable costs The variable costs considered in this analysis are:

1. Fuel consumption. Fuel consumption for the tandem-axle dump truck with pup trailer combination is estimated at 4.75 miles per gallon full and 5.75 miles per gallon empty. This range is shifted 2.5 percent higher and 2.5 percent lower for one-way

trip distances of 5 to 19.99 and 75 to 200 miles, respectively.

2. Oil and oil filter cost. Oil and oil filter cost per change is estimated to be \$33.90. The oil and filter are changed every 20,000 miles.

3. Tire cost. Tire cost and life expectancy by tire size are obtained from tire dealers and truck owners and are as follows:

Size of tire	Ply	No. used	Price	Life
1200/20	18	2	\$305.28	100,000 miles
1100/20	16	16	\$281.14	100,000 miles

4. Driver wages. Driver wages are non-union scale and are estimated at \$6.25 per hour with fringe benefits.

Transfer time   Loading time for the tandem-axle dump truck with pup combination at a conveyor or tipple is estimated at ten minutes. Unloading time is estimated to be eighteen minutes. Loading time on a backhaul involving a front-end loader is estimated to be fifteen minutes.

Average cost per mile and per ton-mile   The estimated costs per mile and per ton-mile for the tandem-axle dump truck with pup trailer are presented in Table 3.7.

Equipment   Tandem-axle dump truck.

Fixed costs   The fixed costs considered in this analysis are:

1. Interest and depreciation costs. Interest and depreciation costs are based on annual equivalent cost using a 10 percent interest rate and a life expectancy of four years for the tractor and eight years for the aluminum dump box. Purchase price less tires for the tractor is \$34,640. Purchase price for the aluminum dump box is \$6,950. Salvage values for the tractor and dump box are \$9,006 and \$500, respectively.

2. License fee. The license fee for this vehicle is \$735 per year. The highway use tax is \$160 per year.

3. Insurance cost. The insurance cost for the tandem-axle dump truck is estimated to be \$1,200 per year.

Table 3.7. Estimated costs of hauling coal in a tandem-axle dump truck with a pup trailer in mid-1977 prices with 0 percent backhaul

Round trip distance	Speed in miles per hour	Number of trips per year	Total annual mileage	Fixed cost per year
Tandem-axle dump truck with pup trailer[a]				
10.00	40	3,055	30,550	$21,850.70
15.00	42	2,659	39,885	21,850.70
20.00	45	2,405	48,100	21,850.70
30.00	46	1,960	58,800	21,850.70
39.98	47	1,665	66,600	21,850.70
Tandem-axle dump truck with pup trailer[b]				
40.00	47	1,665	66,600	$21,850.70
50.00	47	1,434	71,700	21,850.70
100.00	48	861	86,100	21,850.70
149.98	49	623	93,450	21,850.70
Tandem-axle dump truck with pup trailer[c]				
150.00	49	623	93,450	$21,850.70
200.00	51	500	100,000	21,850.70
250.00	52	416	104,000	21,850.70
300.00	53	358	107,400	21,850.70
350.00	55	321	112,350	21,850.70
400.00	55	284	113,600	21,850.70

[a]Trucking cost function for one-way trip distances from 5 to 19.99 miles; α = \$0.3668116, β = \$0.04141312.

[b]Trucking cost function for one-way trip distancses from 20 to 74.99 miles; α = \$0.3711218, β = \$0.04114266.

[c]Trucking cost function for one-way trip distances from 75 to 200 miles; α = \$0.7439178, β = \$0.03603042.

Variable cost per mile	Transfer cost per year	Total cost per year	Average cost per mile	Average cost per ton-mile
Tandem-axle dump truck with pup trailer[a]				
$0.30903	$8,974.06	$40,265.63	$1.318024	$0.001146
0.30159	7,810.81	41,690.41	1.045265	0.000909
0.29167	7,064.69	42,944.66	0.892820	0.000776
0.28865	5,757.50	44,580.80	0.758177	0.000659
0.28576	4,890.94	45,773.17	0.687285	0.000598
Tandem-axle dump truck with pup trailer[b]				
$0.28100	$4,890.94	$45,456.15	$0.682525	$0.000593
0.28100	4,212.38	46,210.68	0.644500	0.000560
0.27823	2,529.19	48,335.35	0.561386	0.000488
0.27557	1,830.06	49,432.88	0.528977	0.000460
Tandem-axle dump truck with pup trailer[c]				
$0.27123	$1,830.06	$49,027.30	$0.524637	$0.000456
0.26623	1,468.75	49,942.35	0.499423	0.000434
0.26387	1,222.00	50,515.42	0.485725	0.000422
0.26160	1,051.63	50,998.65	0.474848	0.000413
0.25732	942.94	51,703.13	0.460197	0.000400
0.25732	834.25	51,916.08	0.457008	0.000397

4. Maintenance and repair costs. Annual maintenance and repair costs are assumed to be 6.7 percent of vehicle purchase price.

5. Management and overhead costs. Management and overhead costs are estimated at \$3.636 per year.

Variable costs The variable costs considered in this analysis are:

1. Fuel consumption. Fuel consumption calculations are based on an estimated 4.65 miles per gallon full and 5.35 miles per gallon empty for the tandem-axle dump truck.

2. Oil and oil filter cost. Oil and oil filter cost per change is estimated at \$33.90. The oil and filter are changed every 20,000 miles.

3. Tire costs. Tire costs and life expectancy by size are obtained from tire dealers and truck owners and are as follows:

Size	Ply	No. used	Price	Life
1200/20	18	2	\$305.28	100,000 miles
1100/20	16	8	\$281.14	100,000 miles

4. Driver wages. Driver wages are non-union scale or \$6.25 per hour including fringe benefits.

Transfer time The average loading time from gate entrance to gate exit for the tandem-axle dump truck is estimated to be 5.0 minutes. Loading is accomplished by front-end loader. The average unloading time for this vehicle is estimated to be 3.5 minutes.

Average cost per mile and per ton-mile The estimated cost per mile and per ton-mile for the tandem-axle dump truck is presented in Table 3.8.

Table 3.8. Alternative II estimated costs of hauling coal in tandem-axle dump trucks in mid-1977 prices with 0 percent backhaul

Round trip distance	Speed in miles per hour	Number of trips per year	Total annual mileage	Fixed cost per year
		Tandem-axle dump truck[a]		
0.50	14	12,520	6,260	$18,763.89
1.00	18	11,250	11,250	18,763.89
1.50	21	10,405	15,608	18,763.89
2.00	25	10,000	20,000	18,763.89
3.00	32	9,411	28,233	18,763.89
4.00	34	8,538	34,152	18,763,89
10.00	40	5,641	56,410	18,763.89
15.00	42	4,425	66,375	18,763.89
20.00	45	3,764	75,280	18,763.89
30.00	46	2,777	83,310	18,763.89
40.00	47	2,219	88,760	18,763.89

[a]Trucking cost function for one-way trip distances from 0.25 to 20 miles; α = \$0.17432192, β = \$0.05776062.

Variable cost per mile	Transfer cost per year	Total cost per year	Average cost per mile	Average cost per ton-mile
Tandem-axle dump truck[a]				
$0.57672	$10,955.00	$33,329.14	$5.324143	$0.007099
0.47751	9,843.75	33,979.64	3.020412	0.004027
0.42791	9,104.37	34,546.85	2.213477	0.002951
0.38029	8,750.00	35,119.68	1.755983	0.002341
0.32560	8,234.62	36,191.24	1.281877	0.001709
0.31411	7,470.75	36,962.23	1.082286	0.001443
0.28654	4,935.87	39,863.48	0.706674	0.000942
0.27910	3,871.87	41,160.98	0.620128	0.000827
0.26918	3,293.50	42,321.16	0.562183	0.000750
0.26616	2,429.87	43,367.51	0.520556	0.000694
0.26327	1,941.62	44,073.23	0.496544	0.000662

Truck Rate Estimates

Truck rates are estimated in this analysis by the following formula:

$$(20)\ R_v = \left[FCT_v + VCT_v(m_v) + TRT_v\right] 1.15$$

where

R_v = estimated rate per ton for vehicle-type v.

FCT_v = fixed cost per ton for vehicle-type v.

VCT_v = variable cost per ton-mile for vehicle-type v.

m_v = one-way trip distance for vehicle-type v.

TRT_v = transfer cost per ton for vehicle-type v.

The α calculated in the truck cost section for each vehicle type and trip distance is equal to $FCT_v + TRT_v$. The β calculations equal VCT_v. Costs are increased 15 percent to estimate 1977 truck rates for transporting coal.

Ex Parte 336 Rail Rates

All rail rates for the transportation of coal used in this analysis are Ex Parte 336 published rates. Rate estimates for high volume shipments generated by the projected expansion in domestic coal demand are not considered in this study. Table 3.9 presents Ex Parte 336 rates for selected coal shipments by rail to and within Iowa.

Table 3.9. Ex Parte 336 rail rates for coal shipments from selected origins to selected Iowa destinations in dollars per ton

From	To	Shipment Size	Rate
Gillette, Wyoming	Sergeant Bluff, Iowa	100 cars	$ 7.73
Gillette, Wyoming	Des Moines, Iowa	50 cars	10.45
Gillette, Wyoming	Burlington, Iowa	50 cars	12.52
Gillette, Wyoming	Burlington, Iowa	15 cars	15.52
Canton, Illinois	Keokuk, Iowa	15 cars	4.05
Sparta, Illinois	Keokuk, Iowa	15 cars	6.72
West Harrisburg, Illinois	Keokuk, Iowa	15 cars	7.45
Nortonville, Kentucky	Keokuk, Iowa	15 cars	8.40
Gillette, Wyoming	Iowa Falls	1 car	16.58
Canton, Illinois	Iowa Falls	1 car	9.70
Nortonville, Kentucky	Iowa Falls	1 car	11.97
Unionville, Missouri	Iowa Falls	1 car	2.18
Hamilton, Iowa	Iowa Falls	1 car	5.95

Barge Rates and Rate Estimates

The barge rates and rate estimates used in this study are presented in Table 3.10. Actual rates were available from industry sources for much of the traffic studied. The methodology for estimating rates for projected barge traffic is contained in recent coal transportation research done at Iowa State University (3). The methodology is as follows:

$$(21)\quad \frac{I_i + Tw_i + Sw_i + M_i}{PL_i} = TTC_i/\text{ton}$$

$$(22)\quad \frac{R_i/\text{ton}}{TTC_i/\text{ton}} = \Theta_i$$

$$(23)\quad (TTC_j/\text{ton})\ (\Theta_i) = R_j/\text{ton}$$

where

I_i = investment costs for barge shipment i. Investment costs are annual equivalent costs using a 10 percent interest rate and a 20-year life expectancy.

Tw_i = towing costs for barge shipment i.

Sw_i = switching costs for barge shipment i.

M_i = other costs for barge shipment i, including insurance on equipment and payload, taxes, administration, and maintenance.

PL_i = payload for barge shipment i.

TTC_i/ton = total trip cost per ton for barge shipment i.

R_i/ton = actual rate per ton for barge shipment i.

Θ_i = a scalar transformation.

TTC_j/ton = total trip cost per ton for barge shipment j for which there is no actual rate.

Table 3.10. 1977 barge rates and estimated barge rates for the transportation of coal to selected river locations in Iowa in dollars per ton[a]

Destinations	Origins		
	Kellogg, Ill.	East St. Louis, Ill.	Grand Rivers, Ky.
Keokuk	\$2.20	\$2.00	\$3.10[b]
Muscatine	2.50	2.30	3.34[b]
Montpelier	2.50	2.30	3.36[b]
Davenport	2.50	2.30	3.29[b]
Clinton	2.32	2.12	3.01[b]
Dubuque	2.57	2.37	3.29[b]
Lansing	2.82	2.62	3.52[b]

[a]C. Phillip Baumel, John Miller, and Thomas Drinka (3).

[b]Indicates an estimated rate.

R_j/ton = estimated rate for barge shipment j.

It is interesting to note that the scalar, Θ_i, is less than one. This indicates that the estimated total barge costs are greater than rates currently in existence. This finding is consistent with recent publications regarding the failure of the barge transport industry to cover capital replacement costs (10, p. 3).

Coal Transportation Costs by Mode Combinations

The principal modal transfer considered in this study is the transfer of coal shipped from the mine by rail to a barge for movement to an Iowa destination. Certain costs are incurred in the unloading and reloading of a shipment that vary with the type of equipment employed. The analysis of joint rates and transfer costs is contained in an unpublished report by C. Phillip Baumel and staff at Iowa State University (3). Table 3.11 presents the joint rates and estimated rates including transfer costs for the rail=barge shipments included in this study.

In addition to the rail-to-barge transfer of a coal shipment, this study also includes an analysis of truck shipment of coal transferred to rail movement.

The transfer costs of loading and unloading depend upon the equipment employed. In this case, the equipment used is a function of the number of cars loaded. Single-car rail loading facilities require a front-end loader. Total fixed and variable costs for the operation of single-car loading facility are calculated assuming a Caterpillar 988 front-end loader, a one-way hauling distance of 100 feet, coal density

Table 3.11. 1977 rail-barge and estimated rail-barge combined rates including transfer costs for selected movements of coal to Iowa destinations in dollars per ton[a]

Destinations	Origins		
	Sparta, Ill.	Harrisburg, Ill.	Nortonville, Ky.
Keokuk	$4.05	$5.50	$6.05[b]
Muscatine	4.35	5.80	6.29[b]
Montpelier	4.35	5.80	6.31[b]
Davenport	4.35	5.80	6.24[b]
Clinton	4.17	5.62	5.96[b]
Dubuque	4.42	5.87	6.24[b]
Lansing	4.67	6.12	6.47[b]

[a] C. Phillip Baumel, John Miller, and Thomas Drinka (3).

[b] Joint rate estimate.

of 1,500 pounds per cubic yard, and a 0 percent grade. The estimated loading cost for the single-car rail facility is $0.28 per ton (5, section 27). This analysis is limited to coal shipment from Missouri mines by truck to Centerville where a transfer to rail movement is anticipated. Truck rates to Centerville from the Unionville, Missouri, area are estimated to be $1.29 per ton.

Variable Coal Receiving Costs

The final consideration in the provision of transportation cost data in this model is an analysis of variable receiving costs at the destination point. These costs vary by mode and size of shipment and from the transport vehicle to a stockpile. Variable coal receiving costs assumed in this analysis are: 1) $0.35 per ton for a single-car rail shipment; 2) $0.25 per ton for a fifteen-car rail shipment; 3) $0.20 per ton for a fifty-car rail shipment; 4) $0.11 per ton for a one-hundred-car rail shipment; 5) $0.05 per ton for a truck shipment; and 6) $0.35 per ton for a barge shipment.

Coal Beneficiation Costs

Plant performance parameters

Plant performance data for the analysis of coal beneficiation cost is derived from an actual "package" beneficiation plant proposed for construction in Iowa (6). The raw coal feed rate is estimated to be 250 tons per hour. The plant is assumed to operate on a double-shift basis of 14 hours per day, 45 five-day weeks, with a down time of 4 weeks per year. Annual consumption of raw coal is estimated to be 840,000 tons. The production breakdown for processed coal is estimated to be 77 percent clean coal and 23 percent refuse and refuse fines resulting in an estimated 646,000 tons of clean coal per year. Sulphur reduction is estimated to be 35 percent while Btu content is upgraded an estimated 12 percent.

Fixed costs

The fixed costs considered in this analysis are based on annual equivalent costs using a 10 percent rate and are as follows:

1. Beneficiation plant. The beneficiation plant used in this analysis consists of one heavy media separator with pumps, drying equipment, a Bradford breaker, a roll crusher, sixteen deister tables, conveyors, scales, radiant heaters, and a fifty-rail car loading out capacity. Estimated purchase price is $2,000,000 with a plant life expectancy of 20 years. Salvage value is assumed to be equal to the cost of dismantling the equipment. Annual equivalent cost for the plant package is $234,920.

2. Front-end loader. The front-end loader used in this analysis is a Caterpillar 988 with a six-yard bucket. Purchase price less tires is estimated to be $158,127. Salvage value at the end of 10,000 hours is estimated to be $63,251. Life expectancy in years is determined by the intensity of use. On a double-shift operation, life expectancy is estimated to be three years. Annual equivalent cost for the front-end loader is estimated to be $44,476.

3. Water impoundment. A 20-acre water impoundment is included in this analysis. Pumps, miscellaneous equipment, and sitework have an estimated cost of $75,000. The actual land involved is considered separately since, by assumption, it does not depreciate. At the completion of the 20-year life expectancy of the beneficiation plant, the salvage value of this investment is zero. The annual equivalent cost for the impoundment and supporting equipment is estimated to be $8,810.

4. Site improvement. These costs involve the grading and concrete work for the structures involved as well as access roads and turnaround areas. The estimated original investment in site improvement is $75,000. Life expectancy is equal to that of the plant, 20 years. No salvage value is anticipated for this investment. The annual equivalent cost for site improvement is estimated to be $8,810.

5. Miscellaneous settling ponds. The small setting ponds necessary for the operation of a coal beneficiation plant have an estimated cost of $50,000. Life expectancy, again, is limited to the plant life expectancy of 20 years with no anticipated salvage value. Estimated annual equivalent cost for this investment is $5,873.

6. Supplemental water well. A supplemental well is necessary for the continuation of operation during dry periods. Installation costs are estimated to be $20,000 with no salvage value anticipated after 20 years. The annual equivalent cost for this investment is $2,349.

7. Utility extension and sub-station upgrading. The operation of a coal beneficiation plant requires three-phase electric power with adequate sub-station support. The selected coal beneficiation sites require an estimated $10,000 in electric utility upgrading. This investment is limited by plant life expectancy to 20 years and has no anticipated salvage value. The annual equivalent cost estimated for utility upgrading is $1,175.

8. Interest on the investment in land. Land value is stable by assumption in this analysis. The purchase of 100 acres at $2,000 per acre requires a $200,000 investment. The opportunity cost of this investment is derived from the assumed 10 percent interest rate and is $20,000 annually.

9. Maintenance and repairs. Annual maintenance and repair costs are based on 5 percent of the investment cost of the equipment, land, impoundment, settling ponds, and supplemental well. This results in an estimated annual maintenance and repair cost of $126,000.

10. Insurance and property tax. Insurance and property tax costs are based upon 2 percent of the undepreciated investment amount. Annual equivalent cost analysis using a 10 percent interest rate was used to depreciate investment. The total investment is estimated to be $2,588,127. However, $200,000 is an investment in land and, by assumption, will not depreciate. The land investment represents

a \$4,000 per year constant base to which annual equivalent cost for property tax and insurance of \$35,444 are added resulting in a total annual equivalent cost of \$39,444.

11. General manager. The general manager is responsible for coal assembly, scheduling, marketing, and distribution for the beneficiation plant operation. The salary for general manager is estimated to be \$35,000 annually.

12. General supervisor. The general supervisor is responsible for the beneficiation plant operation, maintenance, and labor requirements. The salary estimated for this position is \$25,000 annually.

13. Office expense. Expenses for clerical help, office equipment, supplies, telephone, etc., are estimated to be \$25,000 annually.

14. Miscellaneous expenditures. Dust control expenditures, the cost of complying with MESA regulations, and unforeseen expenditures are estimated to cost \$100,000 annually.

Total start-up expenditures for the coal beneficiation plant are estimated to be \$2,558,127 with a locational fixed cost ranging as high as \$339,000 for railroad siding upgrading. Included in the analysis of fixed costs that vary with plant location are those involving: 1) new or replacement rail track; 2) new or replacement rail ties; 3) turnouts; and 4) grading. Table 3.12 presents annualized costs for the fixed costs that vary with plant location. The sum of locational fixed costs and the estimated annual fixed cost for a coal beneficiation plant of \$676,857 results in total fixed costs at a specific location.

Variable costs

The variable costs included in this analysis are:

1. Electric. The beneficiation plant is estimated to require 680 horsepower at 754 watts of electricity per horsepower per hour. The estimated efficiency of the electric motors used in the plant is 80 percent. The 641 kilowatts per hour required at \$0.025 per kilowatt hour results in an

Table 3.12. Fixed costs for coal beneficiation plants that vary with the location of the plant where all costs are annual equivalent costs with an interest rate of 10 percent

Potential beneficiation plant site	Fixed cost associated with potential site
Givin, Iowa	\$34,636
Oskaloosa, Iowa (CNW)	\$32,523
Bridgeport Station, Iowa	\$23,952
Donnelly, Iowa	\$21,470
Durham, Iowa	\$33,994
Tracy, Iowa	\$31,549
Hamilton, Iowa	\$38,552

estimated cost of \$0.083 per ton of clean coal.

2. Supplies. Lime usage in the coal beneficiation process is estimated to be 11 bags per week of operation at \$2.40 per bag. Lime cost is estimated to be \$0.002 per ton of clean coal. Magnetite cost is estimated to be \$46 per ton. An estimated 0.5 pounds of magnetite is lost per ton of coal produced resulting in a cost of \$0.012 per ton of clean coal produced.

3. Labor. The first shift plant operation requirements are four persons, two of which receive wages and benefits estimated at \$12,500 annually, and two receiving wages and benefits estimated at \$10,000 annually. The second shift labor requirements and costs are identical to the first. Total labor costs and benefits, excluding salaried personnel, is estimated to be \$90,000 annually or \$0.139 per ton of clean coal produced.

4. Analysis. A beneficiation plant must be set for a specific type of coal to achieve maximum efficiency. A single plant receiving coal from multiple sources requires frequest analysis of incoming raw coal and the resultant product. Analysis costs are estimated to be \$0.030 per ton of clean coal produced.

5. Front-end loader. Front-end loader size and operation efficiency has a significant effect on plant performance. This analysis postulates a Caterpillar 988 using 11 gallons of fuel per hour at \$0.50 per gallon. Lubricant, filters, grease, and hydraulic oil cost is estimated to be \$0.48 per hour. Tire costs are obtained from both tire dealers and Caterpillar distributors and are:

Type	Ply	No. Used	Cost	Life
L4 $4\frac{65}{35-33}$	24	4	\$4,000	4,000 hours

Front-end loader variable costs are estimated to be \$34,272 per year or \$0.053 per ton of clean coal produced (5, section 27).

6. Profit. An amount of \$0.50 per ton of clean coal produced is the assumed profit associated with the beneficiation of coal in this analysis.

The total variable cost estimated for the coal beneficiation plant is \$0.819 per ton of clean coal produced.

Coal Consumers in Iowa

Estimated coal consumption and projected demands by Iowa coal users were obtained from a survey conducted by Iowa State University in 1977 (3). Table 3.13 lists the coal users in Iowa that have consumed or are expected to consume at least 1,000 tons of coal annually in the period from 1973 to 1985. Table 3.14 presents aggregate consumption data for Iowa coal users during the same period.

Table 3.13. Iowa coal consumers differentiated into industry or utility classification.

City	Name of Industry	Name of Utility
Ames	Iowa State University	Ames Municipal Electric System
Bettendorf	J. I. Case	Iowa-Illinois Gas and Electric
Boone		Iowa Electric Light and Power Company
Bridgeport Station		Iowa Southern Utilities Company
Buffalo	Martin-Marietta Cement	
Burlington		Iowa Southern Utilities Company
Carroll		Iowa Public Service
Cedar Falls	University of Northern Iowa	Cedar Falls Municipal Utility
Cedar Rapids	Wilson Company	Iowa Electric Light and Power Company (two)
Cedar Rapids		Central Iowa Power Coop
Chillicothe		Iowa Southern Utilities Company
Clinton	Clinton Corn Processing	Interstate Power Company
Clinton	E. I. Du Pont	
Council Bluffs		Iowa Power and Light Company
Davenport	Linwood Stone Products Company	
Davenport	Oscar Meyer	
Davenport	Ralston Purina	
Davenport	Kelsey-Hayes Company	
Des Moines		Iowa Power and Light Company
Dubuque	Celotex	
Dubuque	John Deere	Interstate Power Company
Eagle Grove		Iowa Public Service
Humboldt		Corn Belt Power Coop
Iowa City	University of Iowa	
Iowa Falls		Iowa Electric Light and Power Company
Keokuk	Hubinger Company	
Lansing		Interstate Power Company
Marshalltown		Iowa Electric Light and Power Company
Mason City	Lehigh Portland Cement	

Mason City	Northwestern State Portland Cement Company	
Middletown	Iowa Army Ammunition	
Montpelier		Eastern Iowa Light and Power Cooperative
Muscatine	Grain Processing	
Ottumwa	John Deere	
Pella		Pella Municipal Light and Power
Sergeant Bluff		Iowa Public Service
Spencer		Corn Belt Power Coop
Spencer		Spencer Municipal Utilities
Storm Lake		Iowa Public Service
Waterloo	Rath Packing Company	Iowa Public Service
Waterloo	John Deere	
Webster City		Webster City Municipal Light and Power
West Des Moines	Penn-Dixie Cement	
West Des Moines	Marquette Cement	

Table 3.14. Estimated coal consumption in tons for Iowa coal consumers in 1973, 1974, 1975, 1980 and 1985[a]

Year	Iowa Utilities	Iowa Industries	Total
1973	5,278,192	1,309,329	6,587,521
1974	4,744,384	1,150,419	5,894,803
1975	4,997,157	1,342,107	6,339,264
1980	13,751,172	2,381,320	16,132,492
1985	15,856,659	2,588,290	18,444,949

[a]C. Phillip Baumel, John Miller, and Thomas Drinka (3).

CHAPTER IV. RESULTS

The objective function in this study involves the costs of purchasing, transporting, beneficiating, and handling the coal necessary to fulfill the Btu requirements of Iowa coal users. The optimal solution represents the minimum cost inter-State and intra-State system possible within the constraints and assumptions specified. An examination of the feasible set of coal movements considered will facilitate an understanding of the results presented in this chapter. This system of coal movements is summarized as follows:

1. Coal originating at a projected Iowa coal mine may be transported to a coal beneficiation plant by tandem-axle dump truck. One-way hauling distances are restricted by assumption to 25 miles or less. Eight beneficiation plant locations and 26 Iowa coal origins are considered in this study.

2. Coal originating at a projected Iowa coal mine may be transported directly to an Iowa user by tandem-axle dump truck with a pup trailer. The Big Ben Coal Company and Lovilia #4 Coal Company are shaft mines and are assumed to be the only Iowa mines having deposits of sufficient quality to allow future coal shipments direct to Iowa users without being beneficiated.

3. Processed Iowa coal originating at a coal beneficiation plant located at a selected rail siding within the Iowa coal producing area may be transported by tandem-axle dump truck with a pup trailer to an Iowa user.

4. Processed Iowa coal originating at a coal beneficiation plant located at a selected rail siding within the Iowa coal producing area may be transported to an Iowa user by single-car rail shipment.

5. Processed Iowa coal originating at a coal beneficiation plant located at a selected, potential Iowa mine may be transported by tandem-axle dump truck with a pup trailer to an Iowa user.

6. Coal originating in a selected major coal supplying state may be transported to an Iowa user by tandem-axle dump truck with a pup trailer. The out-of-state origins for which truck transportation was considered are Canton, Illinois, and Unionville, Missouri.

7. Coal originating in Missouri may be transported to Centerville, Iowa, by a tandem-axle dump truck with a pup trailer. At Centerville, the coal is transferred to a single-car rail shipment to an Iowa user.

8. Coal originating in a selected major coal-supplying state may be shipped directly to an Iowa user in 1, 15, 50, or 100 car rail shipments.

9. Coal originating in a selected major coal-supplying state may be transported by rail to a Mississippi River barge loading facility. At the Mississippi River, the coal is transferred to a barge for movement to a selected Iowa user with a barge receiving facility. Three barge loading stations and seven Iowa river destinations were considered.

Assumptions

The assumptions used in this study are as follows:

1. The demand for coal by Iowa users is expressed in millions of Btu. Sulphur constraints are expressed as pounds of SO_2 per million Btu. No origin bias is expressed by Iowa coal users. Iowa coal user decisions are based on the minimum cost of satisfying Btu requirements and meeting SO_2 constraints.

2. Sulphur emissions standards are established by the Environmental Protection Agency, Department of Environmental Quality, and individual counties in Iowa. These restrictions vary across the state. Table 4.1 presents the various sulphur constraints that have been assumed in this study and the cities to which they apply.

Table 4.1. Assumed maximum SO_2 emission levels by selected Iowa city.

1.2 pounds SO_2 per million Btu	5 pounds SO_2 per million Btu	6 pounds SO_2 per million Btu	8 pounds SO_2 per million Btu
Sergeant Bluff	West Des Moines	Cedar Falls	Spencer
Council Bluffs	Des Moines	Waterloo	Mason City
Chillicothe	Cedar Rapids	Dubuque	Humboldt
Lansing		Clinton	Iowa Falls
		Davenport	Boone
		Bettendorf	Ames
		Montpelier	Marshalltown
		Muscatine	Pella
		Buffalo	Bridgeport
		Middletown	Iowa City
		Burlington	
		Keokuk	

3. The projected new Iowa coal mines are assumed to have an annual volume of 70,000 tons of unprocessed coal. A maximum of two mines per township is assumed.

4. Iowa coal users are identified as all users with a projected 1980 coal demand in excess of 1,000 tons per year.

5. Rates for coal transportation used in this solution are Ex Parte 336 rail rates, 1977 estimated truck rates, and 1977 existing barge rates.

6. All rail, barge, and truck coal receiving facilities are existing 1977 receiving facilities.

Presentation of the Results

The model complexity necessitates the organization of the results into meaningful categories. The optimal solution specifies a system of coal movements that may be categorized by examining: 1) coal origins and transportation modes; 2) coal origins and assumed user SO_2 emission levels; 3) the consumption level of Iowa-produced coal by selected Iowa coal receiving cities; and 4) the consumption level of externally-produced coal by selected Iowa coal receiving cities.

Coal Origin and Transportation Mode Analysis

The system of estimated 1980 coal shipments to Iowa users involves modal utilization of the following magnitude: 1) truck, 20.7 percent; 2) single-car rail, 11.4 percent; 3) fifteen-car rail, 0 percent; 4) fifty-car rail, 2.3 percent; 5) one-hundred-car rail, 52.8 percent; and 6) rail transfer to barge joint shipment, 12.8 percent. Table 4.2 presents estimated 1980 coal consumption in Iowa classified by origin and transportation mode.

Table 4.2. Estimated 1980 coal consumption in Iowa in thousands of tons by transportation mode or modes using existing transportation rates

Coal origin	Truck	Rail (number of cars) 1	15	50	100	Rail-barge	Total	Percent
Iowa								
beneficiated coal	2,374.3	159.0	0	0	0	0	2,533.3	15.7
raw coal	307.3	0	0	0	0	0	307.3	1.9
Wyoming	0	0	0	376.5	8,545.6	555.0	9,477.1	58.5
Illinois (Sparta)	0	0	0	0	0	1,397.8	1,397.8	8.6
Illinois (West Harrisburg)	0	1,639.7	0	0	0	118.7	1,758.4	10.9
Missouri	671.3	46.4	0	0	0	0	717.7	4.4
Kentucky	0	0	0	0	0	0	0	0
Total	3,352.9	1,845.1	0	376.5	8,545.6	2,071.5	1,6191.6	100.0

The 1980 solution presented in this analysis represents an increase over 1975 domestic coal production of 2,196,600 tons or 341.1 percent.

In 1975, 84.2 percent of Iowa-produced coal was transported by truck. In this solution, the relationship between domestic coal production and truck transportation is estimated to be even stronger, with a projected 94.4 percent of Iowa-produced coal being transported by truck in 1980. The large increase in Iowa-produced coal volume coupled with a 130 percent increase in Missouri-produced coal, which is also transported primarily by truck, results in an estimated 2,810,652 ton per year increase in coal shipped to Iowa users by truck by 1980. Figure 4.1 illustrates the estimated 1980 coal movements from origin to destination by truck. It is interesting to note that only two rail shipments of Iowa-produced coal enter the solution. The single-car shipment to West Des Moines enters the solution primarily because of a low published tariff that is currently being challenged by the railroad as non-compensatory. Spencer, on the other hand, is on the outside of the perimeter within which truck transportation of coal competes effectively with rail transportation, roughly 200 miles under these assumptions. The estimated rate for a tandem-axle dump truck with a pup trailer hauling coal from Hamilton, Iowa, within the coal-producing area, to Spencer is $9.07 per ton. Variable receiving costs at Spencer are estimated to be $0.05 per ton resulting in a transportation bill of $9.12 per ton of coal by truck. The Ex Parte 336 rate for a single-car rail shipment of coal from Hamilton to Spencer is $6.97 per ton with variable receiving costs at Spencer estimated to be $0.35 per ton for a

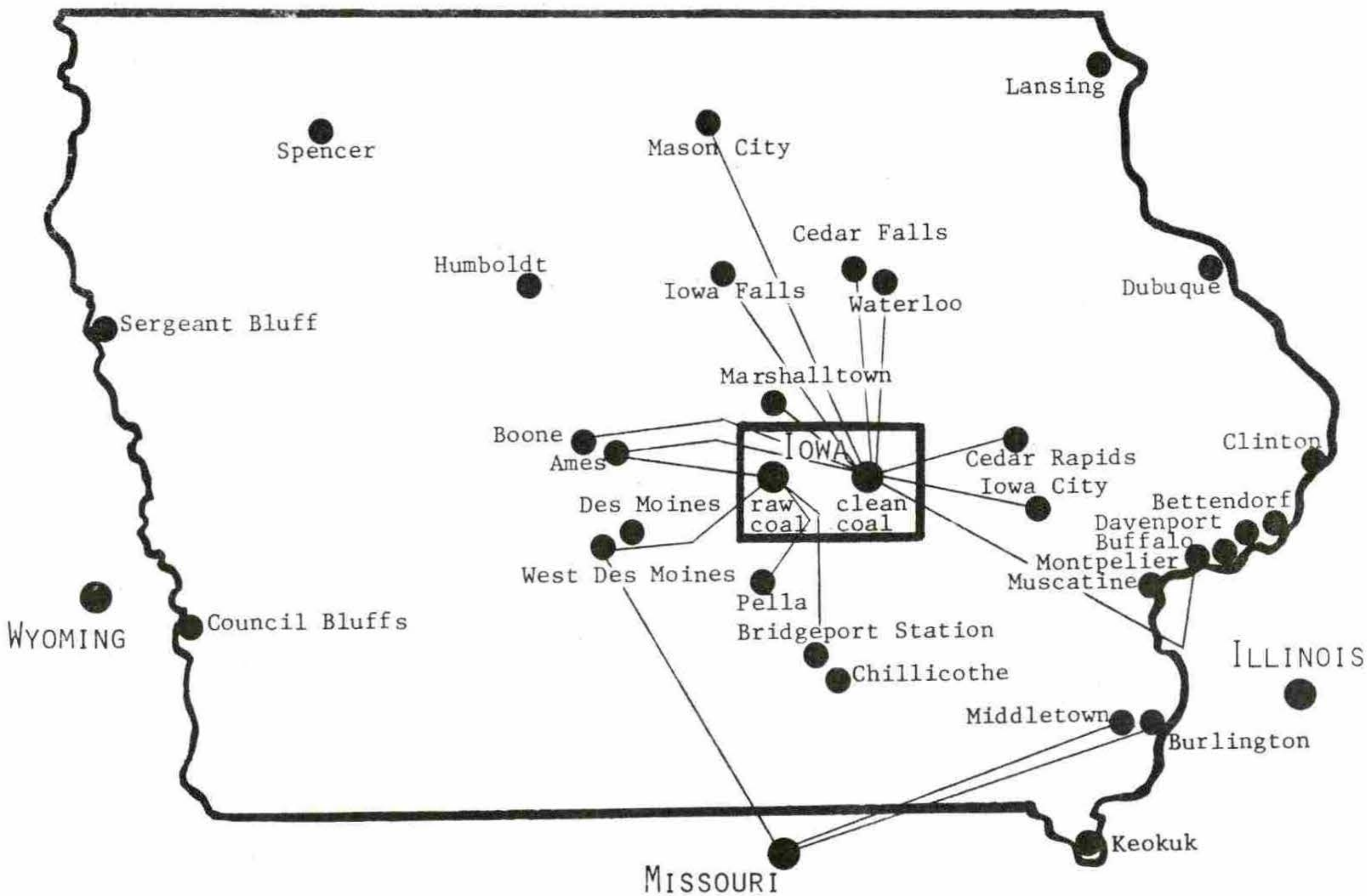

Figure 4.1. Estimated 1980 movement of coal by truck to and within Iowa.

total transportation bill of $7.32 per ton and a clear cost advantage for rail shipment in this instance.

Coal transportation by rail continues as the principal modal choice as projected in this model for 1980. In 1975, 77.2 percent or 5,204,052 tons of coal were shipped to Iowa users by rail. In this solution, 66.5 percent of all coal received in Iowa was shipped by rail transportation. The decrease, relatively, from 77.2 percent to 66.5 percent is a result of proportionately larger domestic coal production expansion and resultant truck transportation of coal. However, rail coal volume increases in this solution to an estimated 1980 volume of 10,767,200 tons, representing a 107 percent increase in coal shipped to Iowa users since 1975.

Figure 4.2 illustrates coal movement by rail in this solution. The 100-car rail shipments represent 52.7 percent of all coal received by Iowa users. This indicates a heavy reliance on Wyoming coal sources and the effect of SO_2 emission constraints on Iowa users.

Rail shipments of coal transferred to a barge at the Mississippi River (hereafter referred to as rail-barge shipments) for movement to Iowa users with barge receiving facilities originate principally in Illinois. In 1975, Iowa coal users received 790,454 tons of coal from Illinois by barge. Western Kentucky also shipped 138,880 tons of coal to Iowa by barge. Aggregate barge shipments amounted to 13.8 percent of total coal tonnage received in Iowa for 1975. The solution generated in this analysis indicates 1980 rail-barge shipments totaling 2,071,500 tons or a 123 percent increase in Iowa coal received by barge. The rail-barge terminology is consistent with the 1975 "water" category presented

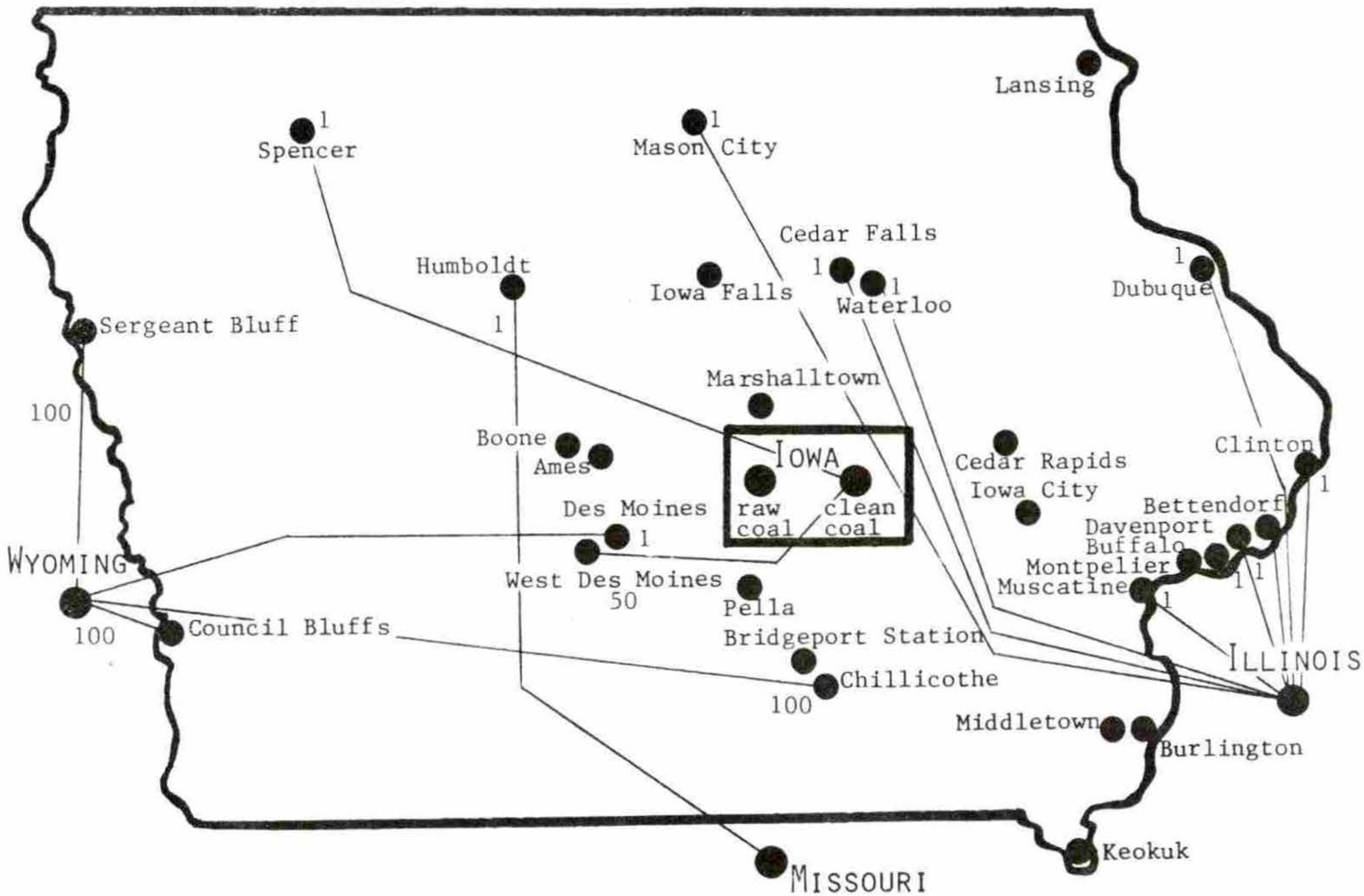

Figure 4.2. Estimated 1980 movement of coal by rail at Ex Parte 336 rail rates. Size of shipment in number of cars is indicated near destination.

in Table 1.1 with the possible exception of the rail-barge shipment from Wyoming. For this 555,000-ton shipment, the rail tariff is a major portion of the transportation bill.

Kentucky coal fails to enter the solution generated in this analysis. Though priced in approximately the same range as Illinois and Missouri coal (see Table 3. 3), the quality advantages Kentucky coal has are negated by higher transport costs in all categories. Figure 4.3 illustrates rail-barge coal shipments projected for 1980 in Iowa.

Coal Origin and Assumed Iowa SO_2 Emission Level Analysis

Iowa coal users are stratified into four SO_2 emission level categories. These levels and associated coal origins are presented in Table 4.3. The Clean Air Act of 1971 established stringent SO_2 emission restrictions of 1.2 pounds SO_2 per million Btu on boiler facilities constructed after 1971. Coal sulphur content becomes the major factor in supplying these facilities. Iowa's major coal consumers, representing 56.9 percent of Iowa's estimated 1980 coal consumption, fall into this category receiving 98.7 percent of their coal in 100-car rail or 100-car rail-barge shipments from Wyoming.

The 5 pound SO_2 per million Btu restriction applies to Des Moines, West Des Moines, and Cedar Rapids in this analysis. These communities comprise an estimated 9.2 percent of the total Iowa market for coal. Iowa-produced coal dominates this category with an estimated 1980 supply of 1,014,700 tons of coal. Coal from nearby sources in Illinois and Missouri did not make a significant impact in this SO_2 category due to

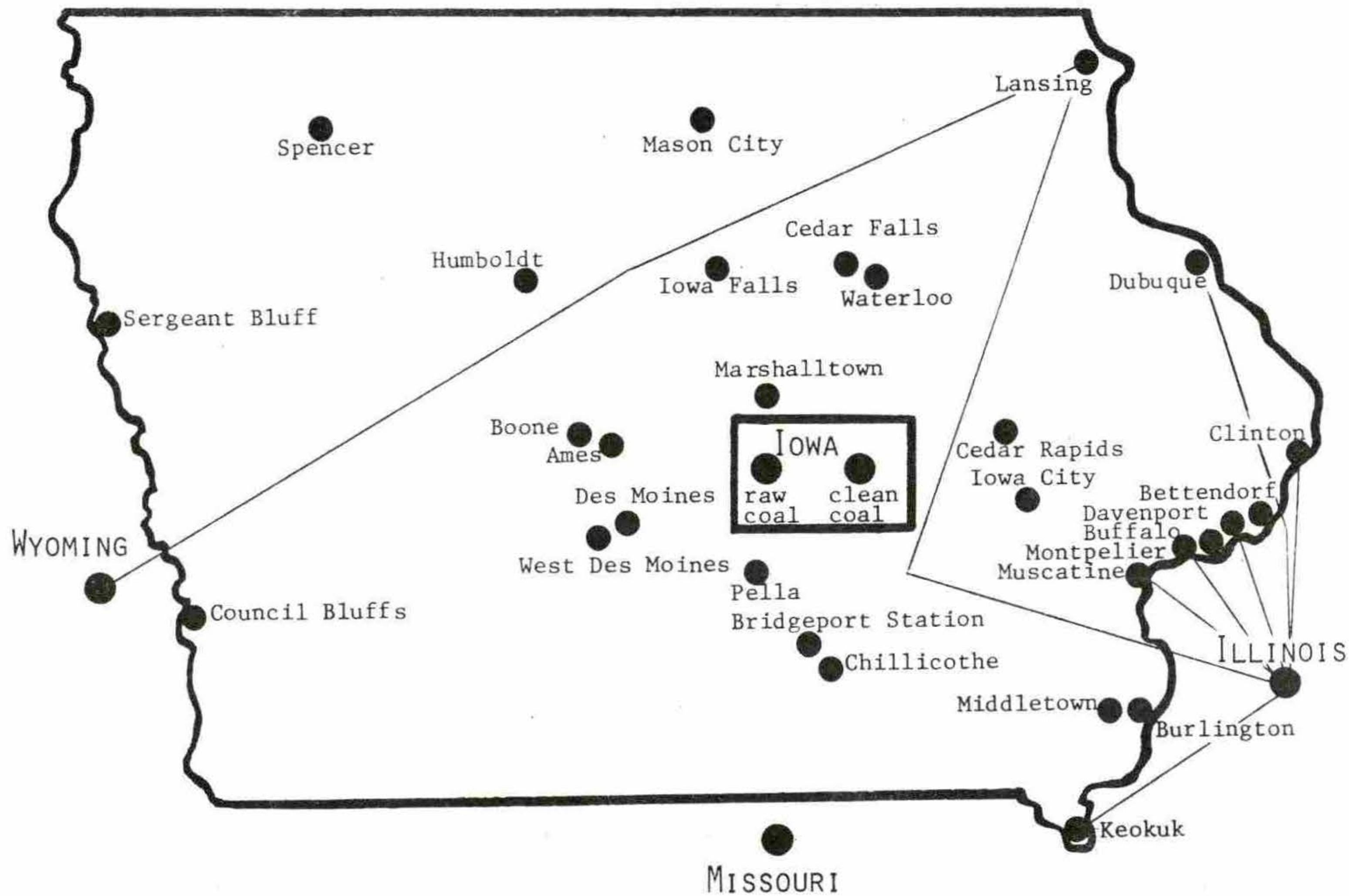

Figure 4.3. Estimated 1980 movement of coal by rail shipment transferred to a barge shipment where the rail shipment is at Ex Parte 336 rate levels.

Table 4.3. Estimated 1980 coal consumption in Iowa in thousands of tons by assumed maximum SO_2 emission levels

Coal origin	Assumed maximum SO_2 emission levels in pounds per million Btu				Total	Percent
	1.2	5	6	8		
Iowa						
beneficiated coal	0	939.4	350.6	1243.4	2533.4	15.7
raw coal	0	75.3	0	232.0	307.3	1.9
Wyoming	9100.6	376.5	0	0	9477.1	58.5
Illinois	118.4	0	2968.8	69.0	3156.2	19.5
Missouri	0	104.7	566.6	46.4	717.7	4.4
Kentucky	0	0	0	0	0	0
Total	9219.0	1495.9	3886.0	1590.8	16191.7	100.0

the proximity of the users to the projected Iowa coal sources.

Six pound SO_2 per million Btu emission constraints apply principally to communities along the Mississippi River, with Waterloo and Cedar Falls being the exceptions. An estimated 23.9 percent of Iowa's 1980 projected consumption can be attributed to these cities. Principal among the suppliers in the 6 pound SO_2 per million Btu category is Illinois with estimated 1980 coal shipments to Iowa of 2,968,800 tons or 76.4 percent of the total in this sulphur category. Again, the proximity of these users to the Illinois coal sources has significant influence on these results. The existence of receiving facilities for comparatively low cost barge transportation also reinforces the Illinois dominance in this sulphur category.

Eight pound SO_2 per million Btu emission constraints are applicable to boilers in existence prior to 1971. The selected Iowa users in this category tend to be geographically situated towards the interior of the state. Iowa coal provides a minimum cost means of satisfying user demand in this sulphur category with, again, a significant transportation cost advantage due to proximity. The 1980 Iowa coal industry supplies an estimated 1,475,400 tons of coal, or 92.8 percent of the total, to users in the 8 pounds of SO_2 per million Btu category.

Estimated 1980 Consumption of Coal Produced in Iowa

The 1980 coal industry projected in this model supplies 89 percent of its delivered tonnage as beneficiated coal and 11.0 percent direct from mine to user as raw coal. Table 4.4 presents the estimated users of Iowa beneficiated and raw coal by user location and the coal shipment transportation mode. Fourteen of the selected coal receiving cities received Iowa-produced coal in this solution. The cities of Cedar Rapids, Marshalltown, and Mason City are the principal consumers of Iowa-produced coal receiving an estimated 57.6 percent of delivered Iowa coal tonnage in 1980.

Estimated 1980 Consumption of Wyoming, Illinois, and Missouri Coal

Nineteen of the selected Iowa coal receiving cities receive coal from Wyoming, Illinois, or Missouri sources in this solution. The major consumers of out-of-state coal are located in Sergeant Bluff, Council Bluffs, and Chillicothe. These communities receive coal in 100-car rail shipments and account for 64 percent of all externally-produced coal consumed in Iowa. Table 4.5 presents estimated 1980 users of coal produced in Wyoming, Illinois, and Missouri by user location and transportation mode. It is interesting to note that West Des Moines receives domestic (Iowa) coal by single-car rail yet receives out-of-state coal by truck (in this case, Missouri, as Figure 4.1 illustrates). This, again, draws attention to the claimed non-compensatory tariff for the single-car rail shipment into West Des Moines discussed in the modal analysis.

Table 4.4. Estimated 1980 users of Iowa raw and beneficiated coal by user location and transportation mode

Iowa user location	Transport mode
Beneficiated coal	
Spencer	Single-car rail
Mason City	Truck
Iowa Falls	Truck
Cedar Falls	Truck
Waterloo	Truck
Boone	Truck
Ames	Truck
Marshalltown	Truck
West Des Moines	Single-car rail
Cedar Rapids	Truck
Iowa City	Truck
Buffalo	Truck
Raw coal	
Ames	Truck
West Des Moines	Truck
Pella	Truck
Bridgeport	Truck

Table 4.5. Estimated 1980 users of non-Iowa-produced coal by user location and transportation mode

Iowa user location	Transport mode
Sergeant Bluff	100-car rail
Council Bluffs	100-car rail
Chillicothe	100-car rail
Des Moines	50-car rail
Lansing	Rail-barge
Dubuque	Rail-barge
Clinton	Rail-barge
Davenport	Rail-barge
Montpelier	Rail-barge
Muscatine	Rail-barge
Keokuk	Rail-barge
Mason City	Single-car rail
Humboldt	Single-car rail
Cedar Falls	Single-car rail
Waterloo	Single-car rail
Dubuque	Single-car rail
Clinton	Single-car rail
Davenport	Single-car rail
Bettendorf	Single-car rail
Muscatine	Single-car rail
West Des Moines	Truck
Middletown	Truck
Burlington	Truck

Estimated 1980 Beneficiation Plant Locations and Coal Assembly Areas

The 1980 solution presented in this analysis selects beneficiation plant sites and their associated coal supply sources. This is accomplished by minimizing the transportation costs of coal assembly and satisfying coal production and supply requirements. An estimated 2,533,300 tons of processed coal originate from the selected plant locations near Donnelly, Durham, Oskaloosa, and Bridgeport Station. Figure 4.4 illustrates these plants and their respective supply areas.

Total raw coal production in this solution is insufficient for the operation of four beneficiation plants at maximum capacity. The processing capacity of four beneficiation plants is estmated to be 2,587,200 tons of coal annually, leaving an estimated under-utilization of plant capacity of 53,900 tons. This slack occurs at the Oskaloosa beneficiation plant indicating an additional need for mining activity within this assembly area. This assumes that a demand exists for additional Iowa coal.

Two potential mines in this analysis supply two beneficiation plants each in the 1980 solution. When plant capacity is reached, a supplying mine with the lowest transportation cost to another cleaning plant will send the remainder of its output to a second plant assuming: 1) that it is within a 25 mile radius, 2) that there is sufficient demand for Iowa coal, and 3) excess plant capacity exists at the second plant.

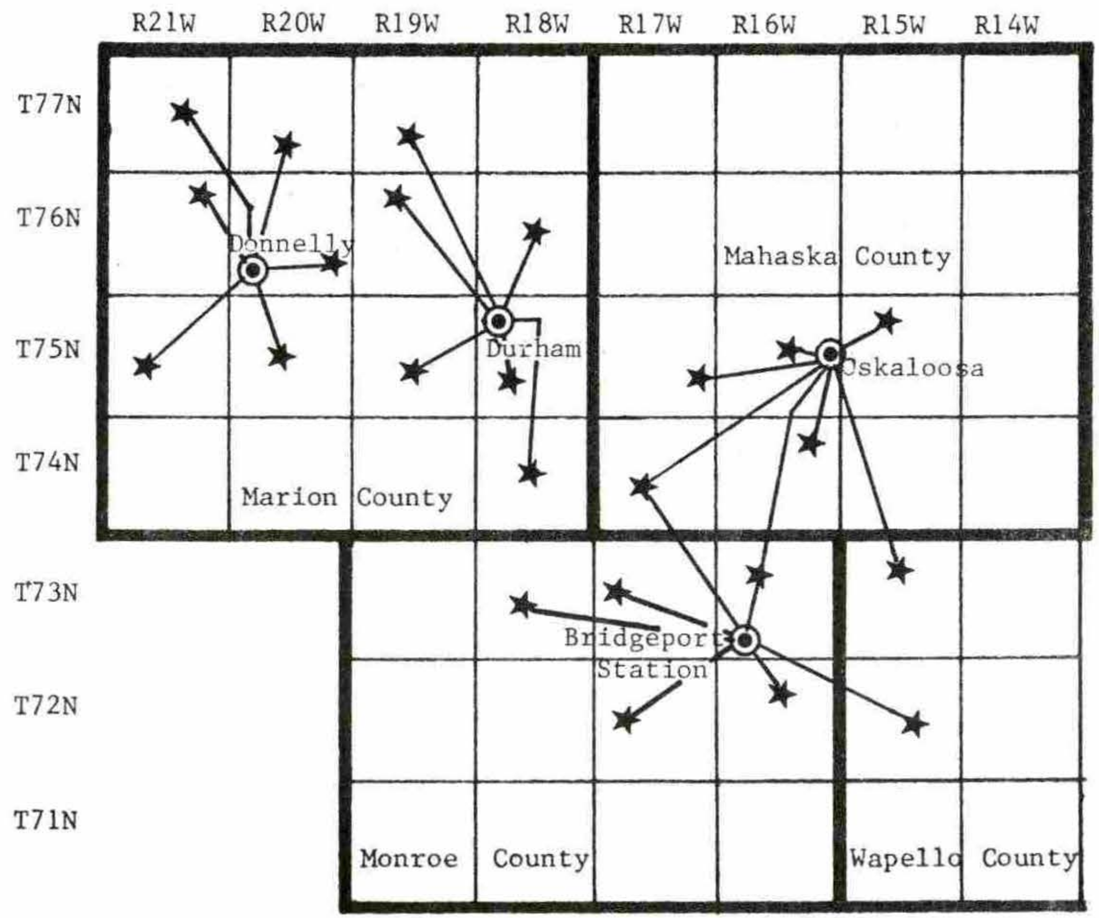

Figure 4.4. Coal assembly areas for the four optimal beneficiation plant locations. Potential mine sites are indicated by a star.

CHAPTER V. SUMMARY AND CONCLUSIONS

The Problem

As energy considerations gain in public attention, researchers across the nation are examining alternate "futures" of fossil-fuel supply and demand. The nation will, of necessity, be shifting its fossil-fuel consumption patterns. Many feel it is the coal industry that will emerge as our primary energy supplier.

The state of Iowa is a net importer of coal today, yet at one time it had a substantial coal industry. Indications are that by 1980, coal consumption in Iowa will increase over two and one-half times as utilities and industries convert existing, or construct new, facilities that are fired by coal.

If current domestic production trends continue, the Iowa net coal deficit will increase alarmingly by 1980. The Iowa net coal deficit represents millions of dollars in expenditures for coal originating in other states. An underlying question in much of the coal research ongoing in Iowa involves the feasibility of redeveloping a substantial Iowa coal industry. It is to this question that this study is, in part, a response.

The problem of estimating the 1980 response of the Iowa coal industry to rapid expansion in demand was divided into four categories for data accumulation. As an initial consideration, an extensive analysis of Iowa's coal reserves was completed to pinpoint, as accurately as current data would allow, a coal-producing area and locations within having the highest probability for surface mining development. Second, a feasible set of coal movements was delineated involving intra-state and inter-state coal shipments by truck, rail, and barge. A transportation cost was calculated for each movement forming the basic matrix for coal delivery from domestic and out-of-state coal origins and for domestic coal assembly for processing at a beneficiation plant. Third, coal beneficiation costs were analyzed and incorporated into the analysis to allow Iowa-produced coal to meet federal SO_2 emission constraints. Finally, Iowa coal users and associated 1980 demands for coal were studied. Important in this analysis were coal-receiving facilities and the federal SO_2 emission constraint that applied to each user.

A linear programming model utilized the four data categories outlined above to accomplish the following major study objectives:

1. Identification of potential Iowa coal sources.
2. Identification of optimal coal beneficiation plant locations, associated assembly and delivery points, and assembly and delivery transportation modes.
3. The identification of optimal origins, destinations, and transportation modes for coal originating outside Iowa.

Summary and Conclusions

The 1980 response of the Iowa coal industry under the assumptions in this model is restricted only by mine output and reserve constraints. All projected mine sources entered the solution at maximum output. A combination of factors involving proximity to user, beneficiation, and low initial price allow domestic coal production to move from supplying

9.6 percent of the 1975 Iowa coal market to a projected 15.7 percent of a significantly expanded market in 1980.

Iowa coal is unable to compete as a supply source for facilities constructed after 1971. These users, limited to a maximum SO_2 emission level of 1.2 pounds per million Btu, are the major consumers of coal in Iowa. As a group, these users account for the dominance of Wyoming coal as a major supply source and rail transportation, specifically 100-car rail shipments, as the principal coal transportation mode. Truck transportation continues as the primary mode for the movement of Iowa-produced coal.

Illinois coal is selected as the second largest supply source of Iowa's estimated 1980 coal consumption. The estimated Illinois coal exports to Iowa in the 1980 solution represent a 4.6 percent increase over 1975. Missouri coal also increases exports to Iowa; however, it continues as a small supplier in this solution with only 4.4 percent of the Iowa coal market. Kentucky coal origins are unable to compete as suppliers in the Iowa coal market in 1980.

Domestic surface-mined coal production must be processed through a coal beneficiation plant in this solution. Four coal beneficiation plants are required if domestic output reaches the maximum indicated in this model. Eight sites were selected as potential coal beneficiation plant locations. Of these, the sites near Donnelly, Durham, Oskaloosa, and Bridgeport Station, Iowa, represent minimum cost locations processing an estimated 3,290,000 tons of Iowa surfaced-mined coal.

Areas of Further Study

The high probability locations projected for Iowa surface mine development in 1980 require extensive coal quality and quantity data. In this analysis, recently produced results of Iowa Geological Survey test boring were used. Such information is highly critical in any projection of future Iowa coal production. Surface mine location, annual production, and coal quality are basic inputs into the model. A determination of sulphur contents in the seven percent range will preclude any Iowa coal from entering the solution. If three mines are allowed in townships with sufficient reserves, Iowa's coal production capacity is substantially increased. Slight surface mine locational shifts may alter the optimum number or location of coal beneficiation plants.

More than any other factor, the accuracy of the type of approach used in this analysis can be increased by more detailed Iowa coal reserve data. In order to properly utilize the township as the unit for data accumulation, coal reserve and quality samples must be gathered on a sub-township, even a section basis.

Coal receiving facilities remain constant in capacity in this solution. Transportation rates, specifically rail rates, are included at 1977 levels. These assumptions are challengeable in light of the significant expansion indicated for Iowa production and demand. It is realistic to assume that volume rate reductions will be negotiated that will allow out-of-state coal supply sources a better competitive position. Volume intra-state transportation by rail may make inroads into the fairly dominant trucking mode in this solution. Any volume rates estimated require additional consideration of fixed and variable costs for receiving facility expansion.

The 1980 solution presented in this analysis indicates a substantial increase in truck shipments of coal. Large volume contracts may encourage larger trucking firms, those operating under the assumptions examined in Atlernative I costs, to enter more strongly into coal transportation Should this occur, the influence of lower transportation rates by truck, characteristic of these users, should be examined.

Coal prices for domestic products reflect current output from Iowa's existing mining companies. New surface mine development, it has been argued, will incur substantially greater costs resulting in higher priced Iowa coal beyond existing capacity. This results in a two-tier pricing system for existing and new surface mine development. This two-tiered price system should be considered at several alternative levels as part of a detailed analysis of domestic price impact.

Iowa has struggled with the issue of 80,000 pound truck standards for a number of years. Though the issue transcends cost savings due to larger payloads, this area should be analyzed for its impact on the objective function and modal relationships to provide more complete information on what may be a substantial Iowa coal industry.

BIBLIOGRAPHY

1. Avcin, Matt. "Iowa coal quality and quantity estimation." Unpublished research. University of Iowa, Iowa City, Iowa, 1975.

2. Baumel, C. Phillip, John J. Miller, and Thomas P. Drinka. An economic analysis of upgrading branch rail lines: a study of 71 lines in Iowa. National Technical Information Service Rep. No. PB-251978/AS, Springfield, Virginia, March, 1976.

3. Baumel, C. Phillip, Thomas P. Drinka, and John J. Miller. "The economics of alternative coal transportation and distribution systems in Iowa." Unpublished report. Department of Economics, Iowa State University, Ames, Iowa, 1977.

4. Boehlje, Michael, and James D. Libbin. "Economics of mining coal in Iowa." Unpublished report no. 47. Department of Economics, Iowa State University, Ames, Iowa, 1977.

5. Caterpillar Tractor Company. Caterpillar performance handbook. Peoria, Illinois: Caterpillar Tractor Company, 1975.

6. Fisher, Ray W., Richard A. Grieve, and Henry Chu. "Iowa coal project preliminary coal beneficiation cost study progress report." Unpublished report. Iowa State University, Ames, Iowa, 1976.

7a. Hanline, D. "An economic determination of the number of sites and site locations for coal blending plants in Indiana." Unpublished Masters thesis, University of Purdue, 1975.

7b. Lemick, John. Composite map constructed from Resource Development Land- and Water-Use Management Eleven-County Region Southern Iowa Map Series 4, Iowa Geological Survey. Earth Science Department, Iowa State University, Ames, Iowa, 1977.

8. Manion, Karen D. "Used tractor prices." Transport Topics 2149 (October, 1976):70.

9. Mining Information Services. 1976 Keystone Coal Industry Manual. New York, New York: McGraw-Hill Mining Publications, 1976.

10. Schrodt, Anita. "Tennessee barge, tow operators seen facing freight rate increases." The Journal of Commerce and Commercial 333, No. 23980 (June 20, 1977):3.

11. Sendlein, Lyle V. A., and Peter R. Johnson. "Report on the location and distribution of coal strip mines in Iowa and implications for future coal explorations." Unpublished report. Iowa State University, Ames, Iowa, 1976.

12. White Motor Corporation. "Personal fuelsaver analyzer." Unpublished fleet survey. White Motor Corporation, 1975.

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